Reducing Lean and Environmental Wastes: The Integration of Value Stream Mapping with Environmental Wastes to Improve Production, Performance, Efficiency and Process Flow

A Thesis by

Timothy James Roosen

A thesis submitted for the Degree of

Masters of Mechanical Engineering

Department of Mechanical Engineering

University of Canterbury

Christchurch

New Zealand

February 2013

Abstract

Current concepts of environmental waste focus on the total production of waste from a production plant or industrial setting and the subsequent consequences on the natural environment. Hence, there is an emphasis on containing waste within the industrial boundaries and applying a post-production process to clean it up. However, waste is generated by individual processes within the production system and can be more effectively treated at this individual site level. Therefore, focused management of environmental waste reduction requires that production engineers first know what the environmental waste is and where specifically it is being generated. However, this is often simply not known with any accuracy. In addition, production plants are controlled and improved by lean methods. Current environmental waste methods lack integration with lean methods and thus are not included in the continuous improvement cycles. Consequently, there is a need to include environmental waste impacts alongside the other primary lean wastes. This work develops just such an integrative method which includes both environmental waste and Value Stream Mapping (VSM). This method was developed and tested in a re-manufacturing setting (i.e. Christchurch Engine Centre, Pratt and Whitney) and is able to represent a variety of environmental wastes. Specifically, it integrates aspects from the generic environmental standard ISO14001 through to an organisational environmental risk register. It provides integration within the VSM process which ensures that the established lean improvement programme (through the use of Kaizen improvements) is focused on specific environmental improvement actions. While the example for this thesis used the factors of carbon footprinting, perceived impact, costs to remediate and waste volumes (both removed from process and residual); the method is capable of being generalised to n^{th} dimension environmental factors. It is thus able to represent a customised environmental waste index for any particular industry. Ambiguous user estimation of waste quantities was accommodated through PERT beta distributions. Several ways to represent the multi-dimensional environmental waste impact data were explored via industry focus group reviews and the preferred representation was designed to completion. The resulting method can be used by production staff to quantify and represent environmental impacts at the level of the individual processes and aggregated to report wastes for the whole value stream. The method may also be used by executives to align organisational practices with strategic objectives for waste reduction.

ACKNOWLEDGMENTS

I would like to thank my primary supervisor Dr. Dirk Pons (Senior Lecturer in Mechanical Engineering at the University of Canterbury; BSc Eng, Msc Med, PhD) and industry sponsor Timothy Coslett (Engineering and IT manager, Pratt and Whitney, Christchurch Engine Centre) for their constant guidance and support throughout the duration of this thesis. They were extremely influential and active in the development and completion of my thesis, providing a solid foundation of support and superb resources to ensure a comprehensive thesis was developed. I would like to also thank the project sponsor Christchurch Engine Centre (Pratt and Whitney) and University of Canterbury for their excellent resources, as well as continuous assistance. I would also like to thank my entire family, specifically my parents, for their endless encouragement in my efforts to finish my thesis. Finally, I would like to thank my partner for listening while I explored my concepts and ideas during the development and production of this work.

DEDICATION

To my family and friends

Learn from yesterday, live for today, hope for tomorrow. The important thing is to never stop questioning.

~Albert Einstein~

Contents

List of Figures

List of Tables

1 Introduction

1.1 Preface

Lean practices seek to reduce waste in a production process. One of the more common lean management tools is the use of Value Stream Mapping (VSM). This tool analyses and delineates the time taken to complete a process with a particular emphasis on time that does not add value to the product. Hence identification occurs of Non-Value Added (NVA) time. VSM is used to reduce task time and subsequently reduce company monetary overheads. VSM focuses on 'time' as a wasted consumable. However, lean processes as a whole are concerned with many other types of waste. Consequently organisations that seek to implement lean processes are typically required to use different lean tools to cover the various waste dimensions of their processes. This invariably means multiple systems with their own implementation, culture, and reporting processes. There is ongoing interest in developing integrated lean systems that avoid this duplication.

One of these areas where better integration is desirable is between the time dimension as covered by VSM and the environmental waste dimension. Environmental waste is only weakly represented in current lean thinking, which tends to simply perceive waste as merely the excess (cost) of the raw materials. However, from the environmental perspective, the type of waste is important because of the different toxicities and effects on the environment. There are also problems in getting any environmental waste considerations embedded in the production activities. For example, collecting data on environmental waste and its impact on the environment is the typical focus. Yet, there is a lack of vertical integration between the organisational data on environmental waste and the processes that originally created the waste (i.e. the source of the waste) as depicted in Figure 1.

.

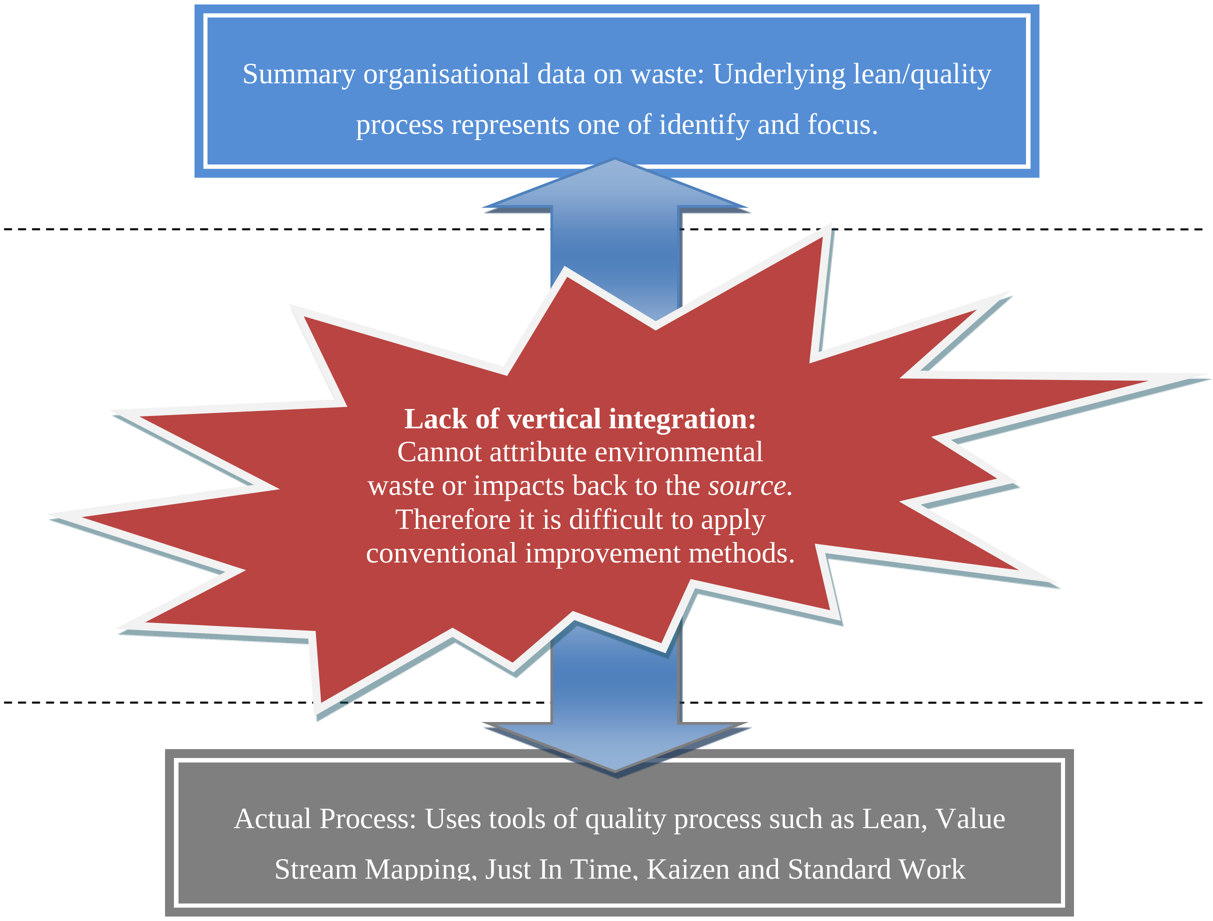


Figure 1: Lack of vertical integration (T. Roosen illustration)

Figure 1 shows that there is a lack of vertical integration between hard organisational data and the process from which the waste originated. This hinders the deployment of sustainability measures through the production system, as well as improving the level of individual processes and operator work teams. This thesis provides a method for the integration of environmental waste into VSM processes through the use of an embedded environmental impact analysis system in an already established lean organisation (see overview of this thesis in Figure 2.) The purpose of this thesis is to amalgamate the concepts of conventional waste management with lean manufacturing waste principles. At the top level, the focus is to propose a methodology to integrate environmental impacts (both positive and negative) into VSM. This creates an Environmental VSM tool (EVSM). Further, this also allows a focus on a waste elimination Kaizen[1] for improvement, not just from a cost saving perspective, but also to promote greener or safer processes.

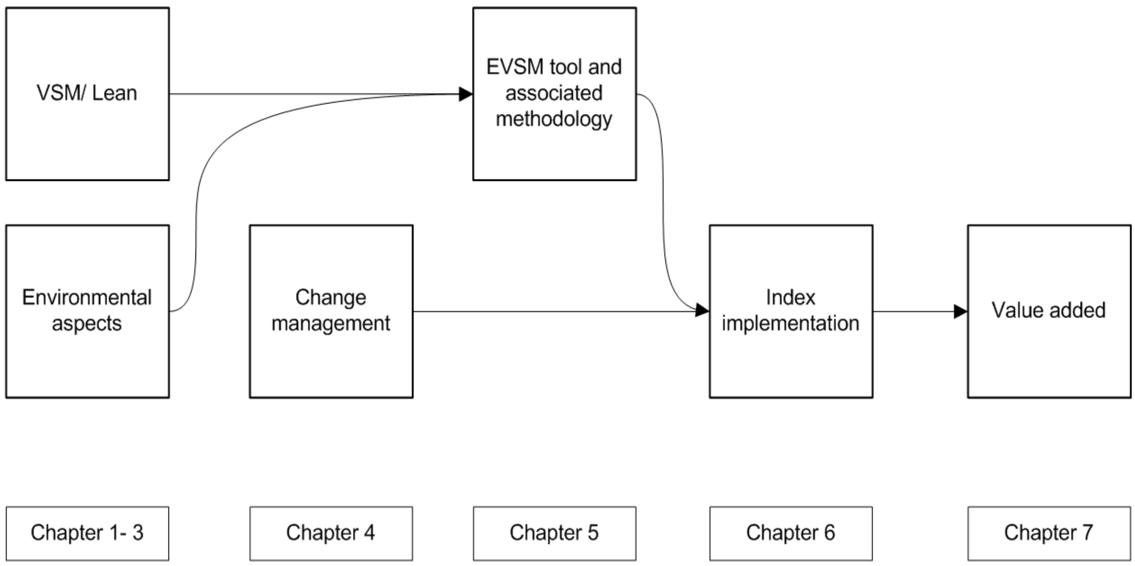


Figure 2: Thesis chapter layout with associated topics covered (T. Roosen illustration)[2]

This thesis also explores the concept that the inclusion of environmental factors into core business operational practices is essential from both a competitive advantage view point, as well ensuring an organisation is morally responsible for the environmental impacts of its processes. It is therefore imperative to find a way to represent waste in a meaningful way, as well as ensure that the practices are adopted within the organisational culture. Thus, it is not just the creation of an environmental mapping tool and integrating the tool. Nor is it deciding the perfect environmental impact factors to include in the tool. Rather, it is important the organisational culture is sensitive to environmental waste. This encompasses an openness to the application of continuous improvement concepts to a lean manufacturing paradigm, alongside the conventional measures of waste.

1.2 Pratt and Whitney business model

The industrial setting in which this project will be applied is the Pratt and Whitney, Christchurch Engine Centre (CEC). The CEC is a maintenance, repair and operations (MRO) facility co-owned by Pratt and Whitney (P&W) and Air New Zealand (Air NZ). Primarily the CEC overhauls three aircraft

---

[1] The term Kaizen is the lean manufacturing principle that comes from the continuous improvement paradigm in which good is never good enough and no process can ever be thought of as perfect. So operations must be improved continuously and excess waste removed from the system.

[2] Environmental Value Stream Mapping (EVSM)

engines: the Rolls Royce Dart turboprop, the JT8D turbofan turbine and the V2500 low-bypass turbofan turbine as shown in Appendix B. The CEC consist of 360 staff occupying over 15,000m^2 facilities spread over three locations with the newest being the facilities for the V2500 line. The turn-around times vary between 44-49 days for the JT8D engine to 55 days for the V2500. The key principle of time dependent processes and distance to the main market is of major importance when considering lean manufacturing concepts such as VSM. A business model diagram of Pratt and Whitney and the CEC is seen in Figure 3..

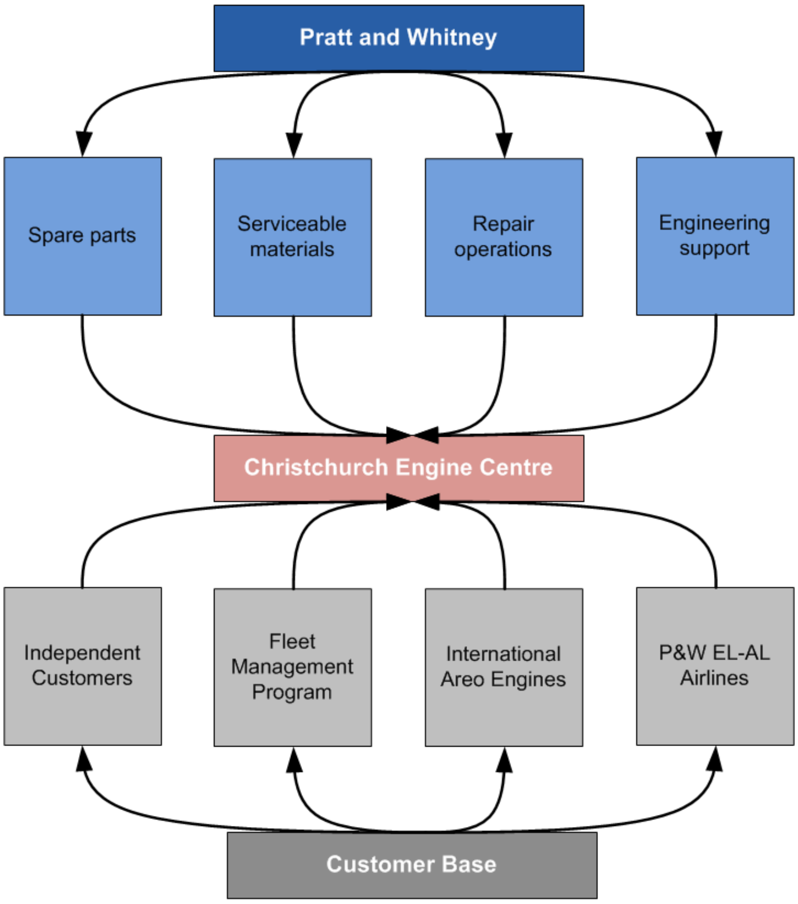


Figure 3: Pratt and Whitney and Christchurch Engine Centre's business model

A breakdown of the business model overview shows the P&W organisational structure, as well as the CEC in relation to both it customer base and the four divisions. The CEC serves as a MRO facility that provides spare parts, serviceable materials, engineering support and most importantly, the primary business of repair services to a large global customer base.

P&W's overall strategic purpose is to provide a highly reliable remanufactured products in as short a time as possible without compromising the overall quality of work. The vision of the company is: "Our Vision: Delivering on our commitments". P&W is committed to providing a dependable service for a wide variety of customers all over the world.

1.3 Business alignment model

Pratt and Whitney and the CEC also have a business alignment model. This business alignment diagram is shown by Figure 4 which further illustrates P&W's and Air NZ's functional split.

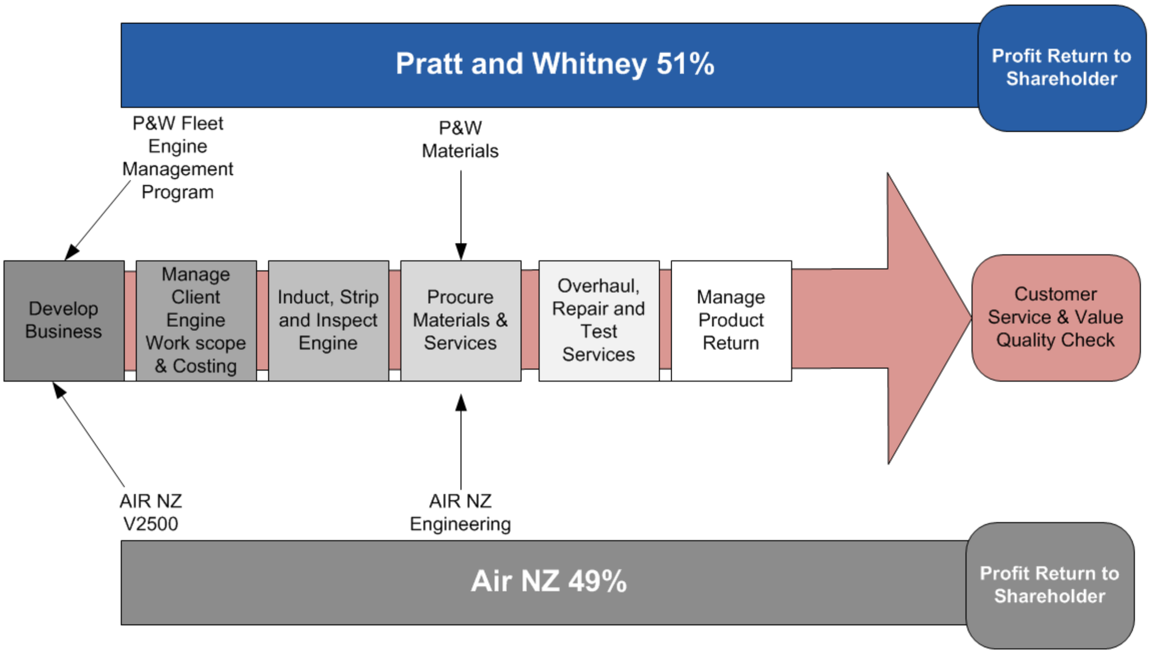


Figure 4: Pratt and Whitney and Air New Zealand (Air NZ) and business alignment model

The business alignment model shows the breakdown of MRO services available at the CEC, along with a representation of the value added from both P&W and Air NZ. The steps for business alignment are as follows:

Step 1: The business alignment objectives begin with the development of business prospects. Air NZ provides engines for the V2500 line whilst P&W provides further opportunities with the Fleet Engine Management Program.

Step 2: Once the clientele base has been established, the client engine costing and work scope can be detailed.

Step 3: The next step is to induct, photograph, strip and inspect the incoming engine so that the work required can be listed and confirmed with the customer.

Step 4 and 5: Procuring materials and services is followed by the main remanufacture stage in which the engines are overhauled, repaired and tested.

Step 6: Once the final testing is completed, the engine can be returned.

Ongoing quality and customer service checks are key aspects in the continuous improvement scheme set up and pursued through Achieving Competitive Excellence (ACE)—the P&W operating system.

ACE is a key productivity improvement tool that relates lean manufacturing concepts (such as VSM) into a fully comprehensive set of tools that employees can use. Not only does ACE provide remanufacture risk reduction, but it also provides a means in which strategic operational risk can be reduced by embedding a continuous improvement 'culture' within P&W. Using lean manufacture tools (such as VSM) is of crucial importance to the CEC due to several factors. The first influencing factor is the location of the CEC compared to their customer base. With an increase in distance comes an increase in transportation costs for both the CEC and the customer. Offsetting this extra transportation cost therefore becomes one of the key success factors for the CEC. The ability of VSM to reduce Non-Value Added (NVA) time and associated costs is thus an invaluable tool in levelling the remanufacture and overhaul costs allowing CEC to preserve a competitive edge in both quality and pricing compared to other MRO facilities closer to an engine's shipping origin.

2 Literature review

2.1 Lean manufacturing waste principles

The perception of waste reduction primarily focuses on the reduction of environmental impacts through the use of traditional waste management programmes. Waste management is most often associated with objects disposed or recycled. In contrast, lean manufacturing aims to reduce costs of production by eliminating Non-Value Added (NVA) activities and is a common underlying principle in many major businesses and production facilities around the world (Womack, Jones et al. 1991; Womack and Jones 1996; Melton 2005; Abdulmalek and Rajgopal 2007). In essence, lean manufacturing preserves value within an organisation by emphasising reductions in time and thus maximising efficiency through the reduction of waste. The development of lean manufacturing techniques originated in the creation of the 'Toyota Production System' (TPS) which focused on pinpointing and eliminating waste (Deming 1986; Womack, Jones et al. 1991; Lian and Van Landeghem 2007). A series of tools were developed to help map and consequently eliminate three areas. These were: 'Muda', also known as the seven wastes, 'Muri' known as the overburdening of people or equipment and 'Mura' known as unevenness or irregular production (Womack and Jones 1996; Hines and Rich 1997; Hicks 2007). The categories developed to describe the seven primary wastes (Muda), plus the eighth waste of underutilisation of people added later in development, are shown in Figure 5, followed by explanations of the terminology (Womack and Jones 1996; Hines and Rich 1997; Womack 2006).

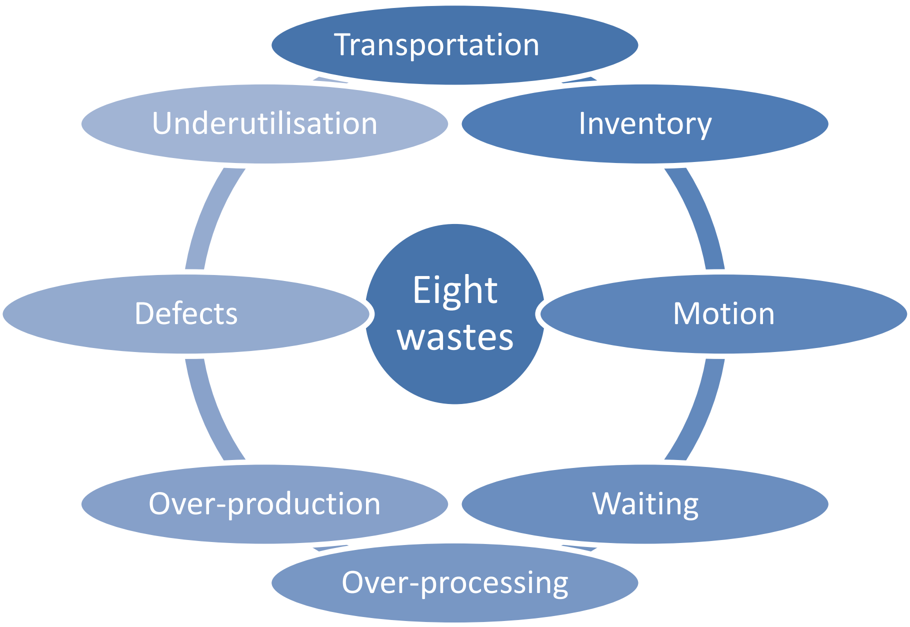


Figure 5: The eight wastes to be eliminated in a lean manufacturing system

- Transportation: Moving a product represents the risk of loss, damage or delay and increasing costs for no added benefit. Transportation does not transform or add value to the product.
- Inventory: Inventory is a representation of raw materials, work in progress (WIP) or finished goods. These three items represent products that have not yet produced an income for the organisation. Waste includes any of these three items not being actively processed.
- Motion: Refers to any movement of a producer, worker or equipment in relation to significant damage, wear or safety.
- Waiting: Waiting describes goods that are stationary in the production system; for example, when they are waiting to be worked on or being processed.
- Over-processing: Over-processing occurs when more work is done on a component than required by the customer. This also includes using more expensive / precise tools or complex systems than are absolutely required.
- Over-production: Over-production occurs when the system produces excess products or more than what the customer requires. One common practice that leads to this waste is the production of large batches, while the customer can change an order during production. Over-production is often viewed as the worst of the seven wastes as it leads to a multitude of NVA activities.
- Defects: Extra cost is always inferred whenever defects are encountered due to reworking the part and / or rescheduling production.
- Underutilisation of people: This waste is called 'plus one' and was established after the original seven. This occurs when there is a failure to productively use people's time within the organisation.

Once the waste identification has been completed, the next step is to determine the root cause[3] or causes. One typical root cause analysis uses the 'five whys' principle. The process begins with the identification of a specific problem, followed by asking why that particular problem happens. If the answer does not identify the root cause, then the engineer or project manager keeps asking 'why' until a root cause is identified (Chen, Ye et al. 2010). Other forms of root cause analysis methods include: Fault Tree Analysis, Failure Mode and Effect Analysis and Event or Success Tree Analysis. Once the root causes have been successfully determined, the final event to take place is a Kaizen activity. In this context, the term Kaizen describes the concept that good is never good enough and that no process can ever be thought to be perfect. So therefore each process must be continually evolved and improved. The term Kaizen in lean manufacturing is used to describe the burst of activity or specific event designed to eliminate the identified waste.

[3] Root cause is an initiating cause of a causal chain of events which leads to an outcome or effect of interest.

The impact and skills development of lean manufacturing has greatly expanded. "Lean manufacturing is one of the most influential new paradigms in manufacturing and has expanded beyond the original application on the shop floor of vehicle manufacturers" (Hines, Holwe et al. 2004). The lean production paradigm can be accomplished by applying a wide variety of lean manufacturing tools. Examples of these tools include: Heijunka, Six Sigma, Kanbans, First In-First Out (FIFO), Value Stream Mapping (VSM), Takt (from Taktzeit meaning cycle) time, Just In Time (JIT), Single Minute Die Exchange (SMDE), 5 S principles and Supermarket systems which are illustrated in Figure 6 (EPA 2003; Abdulmalek and Rajgopal 2007).

Figure 6: Common tools used to implement a lean manufacture system derived from Toyota Production Systems (TPS). (T. Roosen illustration)

The tools themselves are a vital component of lean implementation along with the defining culture of lean practices. One cultural element is the continuous improvement ideology associated with lean systems in which processes are continually analysed and improved. There has been a continuous development and evolution of the lean production tools but no unanimously agreed classification and integration of all the techniques has been developed as yet. There have been many attempts to explore the effectiveness of different techniques used to implement lean thinking in a real practice, along with examining why some techniques might be preferential to others (Lasa, de Castro et al. 2009). Lasa, De Castro et al found that the lack of confidence in the ability of the lean concepts to improve system design and the lack of any real perceived benefit as payback were major influencing factors when organisations were choosing which management tools to use. This paper seeks to demonstrate real benefit in the application of VSM lean principles to environmental wastes.

A primary focus of this literature review is on the lean production tool Value Stream Mapping (VSM) which is highlighted in the next few sections.

2.2 Value Stream Mapping (VSM)

Value Stream Mapping is often viewed as a tool used to map an entire process or supply chain network; mapping both material and information flow that controls production (Braglia, Carmignani et al. 2006).VSM is a functional method or visual flow chart by which lean manufacturing principles can be implemented using a set of standard icons and a means in which information or material flow can be mapped (Tapping, Luyster et al. 2002; Lian and Van Landeghem 2007). The method excels at showing the time dimension, particularly the Non-Value Added or wasted time. It is therefore the lean method of choice for industries where costs are mostly determined by time, or where a shorter production cycle provides a competitive advantage. VSM can map an entire process, supply chain network, or the sub-tasks within a single process. As noted, it readily scales hierarchically using a set of standard icons for information and material flow (Womack and Jones 1996; Rother and Shook 1999; Tapping, Luyster et al. 2002; Lian and Van Landeghem 2007). A given value stream includes all activities that contributed to a product, i.e. Value adding (VA), Non-Value Adding (NVA) and supporting activities that are required to render the service (Seth and Gupta 2005; Kuhlang, Edtmayr et al. 2011; Singh, Garg et al. 2011). The concept of waste within a manufacturing or information system can be further expanded through a categorisation of NVA work, Necessary but Non-Value Adding (NNVA) work and finally VA work (Monden 1993; Womack and Jones 1996).

Using these principles, the baseline processes within the value stream can be established and categorised. Once the value stream has been mapped, it becomes the baseline for improvement which then can be used to help create a future state map. A future state map is an implementation road map to improve process or information flow efficiencies and reduce waste (NNVA and NVA) within the system. A VSM can be broken down into five steps that can then be applied to information, material or process flow. A brief summary of the five steps is provided along with a visual representation shown in Figure 7(Womack and Jones 1996; Rother and Shook 1999).

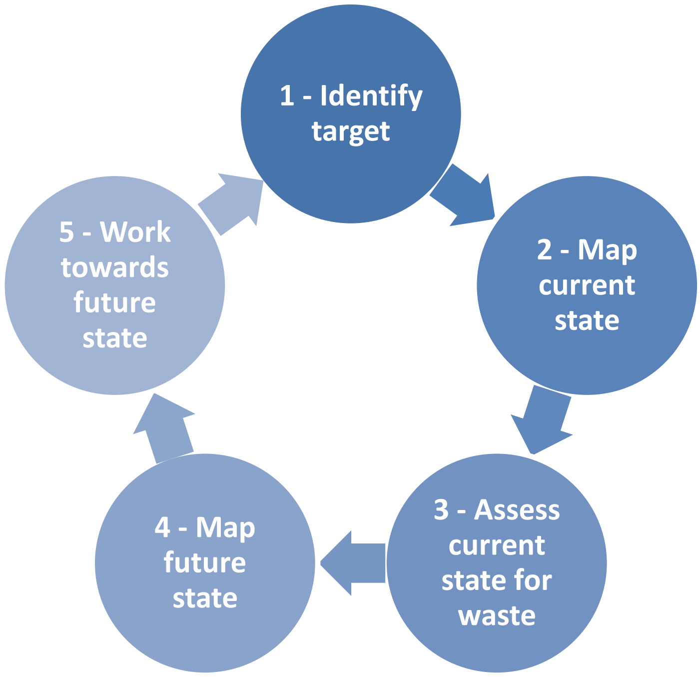


Figure 7: Flow chart diagram representing stages of the Value Stream Mapping process (T. Roosen illustration)

2.2.1 Identify target product, family or service

This stage requires the translation of customer requirements into process requirements. The customer base can be both external and internal and is described as those who accept, evaluate, install / inspect, own and use products or services.

2.2.2 Map current state

Creating a current state VSM requires a team of people (who both manage and support various parts of the value stream) and who have been closely associated or involved with the process or information flow. A mixture of people must be chosen to create a comprehensive current state map. The selection must include people who actually do the work surmised in the map, not just the managers or team leaders. Once the critical value stream has been chosen, every task or component is noted in the order that it is required to complete the service or product. This starts at the shipping stage and works backwards in the value stream to the raw materials or suppliers; while collecting information at each stage. Depending on the type of value stream (e.g. an information flow map or manufacturing value stream), a different set of data should be examined and noted when determining the particular set of operations. For example, for operations primarily concerned with information flow, the following typical data should be collected (Seth and Gupta 2005; Braglia, Carmignani et al. 2006)

- Type of orders released by customer
- Type of orders released to first tier suppliers
- Ordering frequency

- System used to plan production
- Time frame to plan production
- Percentage of information complete and accurate.

For value streams that are primarily machine based, the following typical information should be collected:

- Set up time
- Up time
- Cycle time (process time)
- Delays (wait and / inventory amount)
- Number of operators
- Number of shifts / hours per day
- Percentage complete and accurate.

Finally, for production flow Value Stream Maps, the typical data collected should be:

- Average customer demand
- Shipping frequency
- Pallets dimensions
- Production batches
- Inventory levels
- Type of flow between machines (push-pull[4]).

2.2.3 Assess current VSM in terms of creating a better flow by eliminating waste

Once the current state map has been completed, an assessment should be carried out to determine which processes add value. This step requires the identification of all Value Added (VA) and Non-Value Added (NVA) activities, as well as Necessary but Non-Value Adding (NNVA). A common exercise used during this operation is the lean implementation tool called a Kaizen burst in which areas that represent large amounts of NVA time (lead time) are targeted and reduced or eliminated. An example of a current state Value Stream Map is shown in Figure 8.

[4] Push means 'Make to Stock' in which production is not based on actual demand. Pull means 'Make to Order' in which production is based on actual demand.

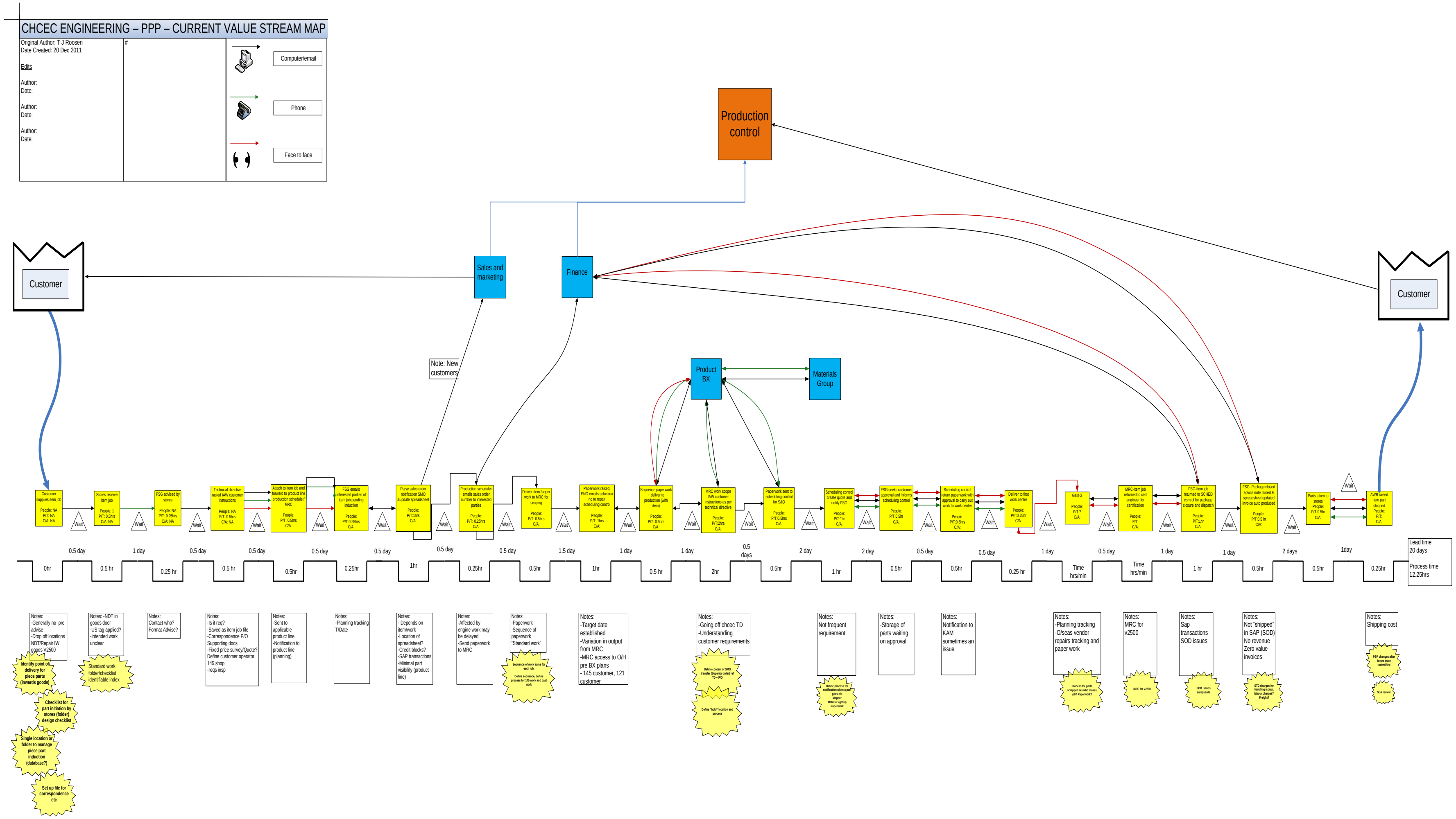


Figure 8: Example of current state Value Stream Mapping for the Piece Part Process at the Christchurch Engine Centre, Pratt and Whitney.

2.2.4 Draw future state VSM

Once the target waste areas are identified, an ideal future state map (FSM) should be determined. This map should represent how the value stream will look after the identified waste has been eliminated. The FSM should be indicative of a situation in which all the individual processes produce only what its customer / process needs (or as close as possible) and only when required.

2.2.5 Work toward the future state condition

The final stage in VSM analysis is the creation and implementation of a work plan to accomplish the waste reduction goals identified whilst determining the FSM. The implementation plan describes how the goals set whilst creating the FSM are going to be achieved.

Waste identification is a crucial element of any VSM, as it is indicative of the Kaizen events used to reduce NVA activities. In this circumstance, a Kaizen event is one in which a process is critically reviewed to determine areas which could be improved. Some common reasons for waste within an information or manufacturing system are listed below (Oppenheim 2004):

- Push rather than pull based specifications and requirements
- Non-optimal use of human resource (e.g. using the wrong staff to do the wrong job such as a manager level or high engineering level staff doing NVA or NNVA work.)
- Lack of detail, lack of organisation in planning, lack of leadership and management
- Use of obsolete two-dimensional drawings instead of a single-point-release database with three-dimensional data.

2.3 Environmental VSM

Environmental indexing or waste categorisation is a relatively new field with respect to Value Stream Mapping applications. The original purpose of a VSM is to identify waste within a given system primarily focusing on time which in turn impacts money. The idea of an Environmental Value Stream Map (EVSM) is a recently developed concept that can be used as a sustainability management tool specifically designed to map environmental waste (e.g. material usage or emissions loss). The United States Environmental Protection Agency (EPA), proposed a model in which the VSM process is adapted to incorporate material consumption (EPA 2011). An example of the modified method is shown in Figure 9.

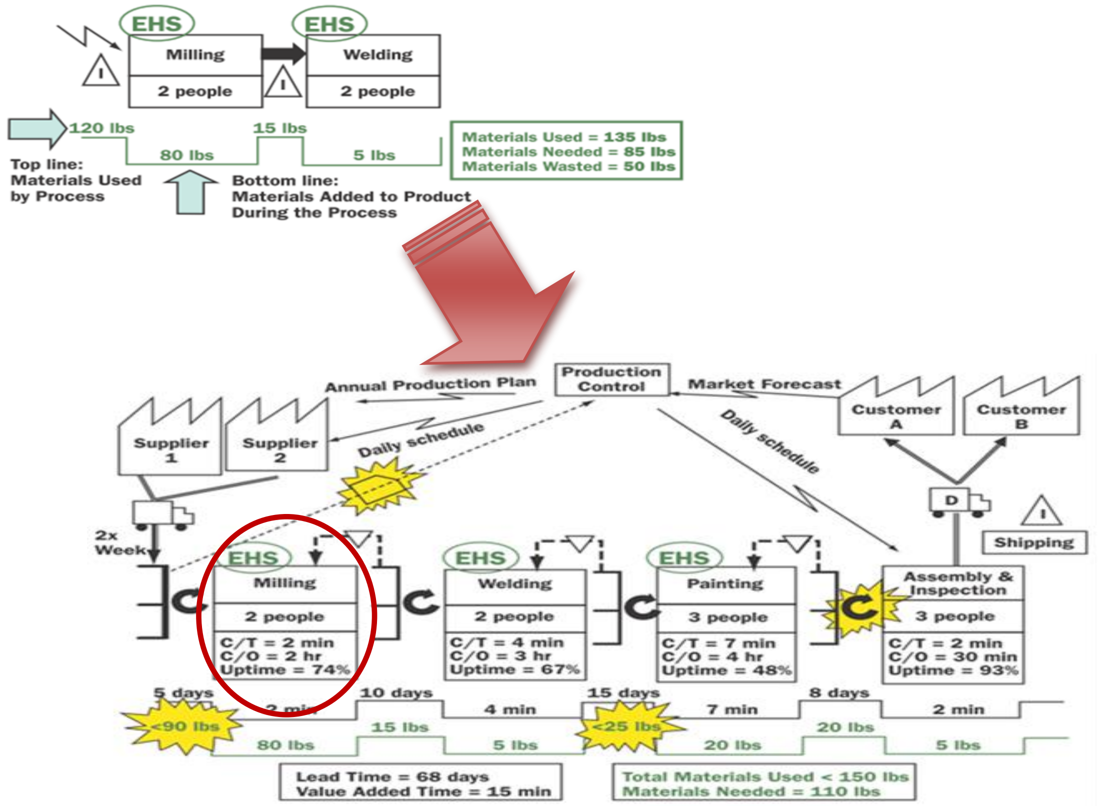


Figure 9: An example of a material consumption modified Value Stream Map with a data acquisition[5] box circled in red (EPA 2011).

The EPA guideline states that there are five ways in which natural resource waste can be addressed using the VSM process. The five factors are listed below.

- Use icons to identify processes with Environmental, Health and Safety (EHS) opportunities
- Record environmental data for processes in VSM
- Analyse materials used versus those needed
- Expand application of VSM to natural resource flow
- Find lean and environmental opportunities in futures state VSM

The EPA toolkit also identifies several types of environmental metrics that can be monitored individually as shown in Figure 10.

[5] The data acquisition box collects the dependent variables of each analysis such as: cycle time, lead time, uptime percent and number of people working at each stage of the process.

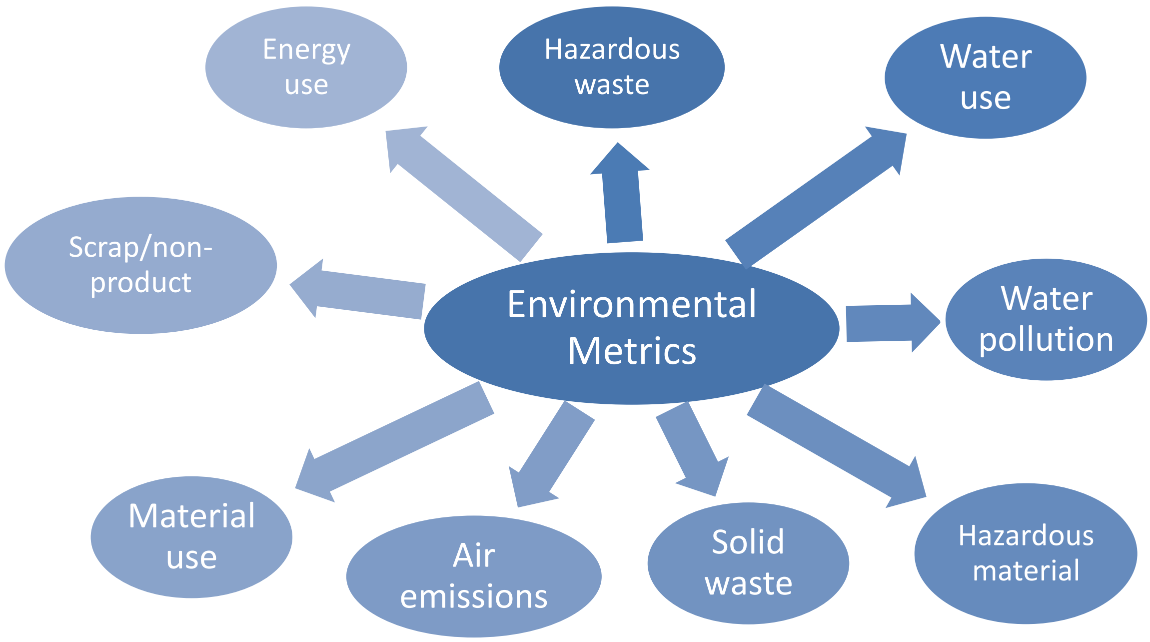


Figure 10: Proposed environmental metrics by US EPA. (T. Roosen illustration)

The method proposed by the EPA was further explored and applied to an alcohol and sugar industry case study in an effort to align economical and environmental VSM processes (Torres and Gati 2009). The application study found that the EVSM method was able to identify areas where wasted water could be decreased by between 24 - 40% as a result of rectifying poor evaporation temperature control systems. This had an impact on the economical factors of the company.

There is a growing awareness of the importance of incorporating environmental factors into lean practices. There have been a number of initiatives in this direction. One such initiative was to use an Integrated Definition for Function Modelling (IDEF0) notation to show a general method to incorporate a pre-determined waste index when using VSM (Patil 2002). The work showed that it was conceptually possible, but much remained to implement environmental factors into operational practices in a real industrial setting, along with the creation of a custom index. Several clear limitations existed. These included: developing a clearly defined industry-based method for environmental impact index incorporation into a VSM, creating a customised agglomerated index and implementing the system in an industrial setting. The IDEF0 method expressed index creation in general terms relying on input from 'environmentalists' to determine the value stream to focus on, as well as relying on an already existing environmental index to determine process level impacts. There have been only minor developments in creating a custom value stream environmental impact index and embedding it into an existing industrial based methodology, such as the lean processes. Thus, what is needed is a way to include environmental waste alongside the other lean wastes. If this is achieved, then the organisational momentum and culture that sustains the lean initiatives will automatically ensure that environmental waste is included in the decision-making.

2.4 Strengths of VSM

Many articles have been written comparing the relative strengths and weaknesses of VSM as an implementation tool for lean manufacturing. Some of the primary strengths found from the literature review are summarised below (Lasa, de Castro et al. 2009; Gurumurthy and Kodali 2011) (Singh and Sharma 2009).

- VSM has the ability to easily identify areas in which waste can be removed within a value stream in terms of reduction in NVA time and consequently overall cost of operations.
- VSM can establish linkage between the information flow and material flow.
- VSM allows an organisation to understand and guide how the information or material flow might evolve in the future if all the improvement activities are implemented properly and identified wastes are eliminated.
- VSM helps an organisation see more than just waste, while mapping helps organisations see the source of waste and identify root causes.
- VSM provides the ability to visualise or clearly see the entire information/material flow and system dynamics (simple and objective analysis).

2.5 Limitations of VSM

As with all processes, VSM has associated weaknesses inherent within the system design that limit the ability of it to be applied in every circumstance. A variety of the limitations inherent in VSM are described below (Irani 2004; Serrano, Ochoa et al. 2008; Lasa, de Castro et al. 2009; Gurumurthy and Kodali 2011; Singh, Garg et al. 2011).

- VSM is a static analysis tool in which one moment of time is captured, not a continuous flow of information. For example, on any given time or day, a particular production plant might be running at lower or higher efficiency than standard due to extenuating circumstances e.g. late delivery, ill staff, machinery failure. In this scenario, VSM tends to mirror the prevailing circumstance or state of the organisation at that moment in time.
- The future state map is drawn on the presumption that all the work identified within the current state map is resolved. Yet, in most normal circumstances, this is never the case with only partial completion of the original goals being achieved.
- Creating, changing and displaying VSM by hand (as required) is often a long and cumbersome process that takes a substantial amount of time to complete.
- The level of detail and ability to capture multiple complex value streams (network mapping) is very limited. The VSM process struggles to handle a complex multi-level information operations (process charts and flow diagrams) or complex bill of material operations.

- VSM is not able to show the spatial layout of a factory or plant and how this might impact inter-material handling delays.
- Theory does not always line up with reality. A large gap still exists between the theory proposed originally in VSM literature and real world usage and applications.

2.6 Gaps in body of knowledge

Although a lot of research and work has been carried out in the past decade with respect to VSM, there are still areas in which knowledge is limited. VSM is widely recognised in many different organisations irrespective of the type of system under examination. Current research has primarily been focused on push / pull, Kanbans, inventory control and mixed model assembly implementation. There has however been less research into adapting concepts such as JIT, continuous improvement, cycle time reduction, visual management, automation, and floor space reduction into VSM simulation (Gurumurthy and Kodali 2011). Another commonly recognised flaw in VSM is the lack in ability to map both complex value streams and value streams other than cycle time or cost. A limited amount of modified VSM concepts have been developed to cope with complex value streams primarily network value mapping and critical path VSM.

The United States Environmental Protection Agency (EPA) has developed an expanded VSM method which looks at trying to map natural resource flow by expanding the mapping process to include environmental waste streams. This method can easily focus on one particular form of waste, but lacks the ability to focus on environmental waste as a whole or even on multiple environmental waste streams. There has been only minor development in creating an overall value stream environmental index with limited attempts at such an adaptation. This then is the goal and focus of this paper—to create an overall value stream environmental index which can be applied in a variety of applications facilitating the creation of a Kaizen event so that waste in production and information systems can be eliminated.

3 Incorporating environmental waste

This chapter looks at the existing methods for lean manufacturing as they relate to industrial waste management methods and contains two sections. The first section is a detailed literature review into lean manufacturing waste management concentrating on the development of waste management methods, and in particular the exploration of waste environmental indexing. The second section contains a brief application case study. This study provides insights into the incorporation of a waste index, aggregate or appropriate scale in alignment with Value Stream Mapping (VSM) principles to provide a new tool for the Christchurch Engine Centre (Pratt and Whitney) to use in lean manufacturing waste management. The study also includes an associated exploration of possible visual representations of the developed index that can be incorporated into current VSMs.

3.1 Waste categorization, context and quality processes

The precise definition of the term “waste” is fluid concept that changes in both form and function depending on the circumstance in which the term is applied. Waste in the context of household goods often includes organics, landfill rubbish and recyclables. For a remanufacturing facility, waste takes on the form of physical material waste, such as emissions and solid wastes, as well as the lean forms of waste such as over-processing, over-production, wasted time and cost. However, a sound definition provides the foundation for which scientific analysis can be carried out. Thus, to further characterize the concept of waste, a set of definitions as defined by the European Union (EU), Basel Convention and the Organisation for Economic Co-operation and Development (OECD) have been summarised in Table 1 (Bontoux and Leone 1997).

Table 1 - Definitions regard the term ‘Waste’ as defined by the Basel Convention, EU and OECD.

Organisation	Definition
Basel Convention (UNEP)	‘Wastes’ are substances or objects which are disposed of, or are intended to be disposed of, or are required to be disposed of by the provisions of law.
European Union (EU)	‘Waste’ shall mean any substance or objective, in which the holder discards or intends or is required to discard.
Organisation for Economic Co-operation and Development (OECD)	“Waste refers here to materials that are not prime products for which the generator has no further use for its own purpose of production, transformation or consumption, and which he discards, or intends or is required to discard. Wastes may be generated during the extraction of raw materials, during the processing of raw materials to intermediate and final products, during the consumption of final products, and during any other human activities.” This excludes residuals directly recycled or

	reused at the place of generation and waste materials that are directly discharged into ambient water or air).

The three definitions of waste described in Table 1 adequately cover how waste is recognised by political bodies and international laws. However, it is somewhat lacking when considering the broader context of waste in a manufacturing environment other than just discarded materials. The OECD definition of waste develops a broader understanding of waste by describing *why* the holder wishes to dispose of the waste. This definition is further expanded by scholarly interpretations of the waste in which the *purpose* or *intent* of disposal is explored rather than just the substance. The proposed definitions separate waste into four categories (Pohjola and Pongrácz 2002; Pongrácz and Pohjola 2004).

- Non-wanted things created, not intended, or not avoided, with no purpose.
- Things that were given a finite purpose; thus destined to become useless after fulfilling it.
- Things with well-defined purpose; but their performance has ceased being acceptable.
- Things with well-defined purpose and acceptable performance; but their users failed to use them for the intended purpose.

Traditionally, organisations focus on the forms of waste that are unusable waste and intended to be discarded as 'rubbish'. Figure 11 further illustrates a small sample of some of the more common forms of waste. For the purpose of this project, waste will be considered as "non-wanted things that are perceived to have no purpose or value".

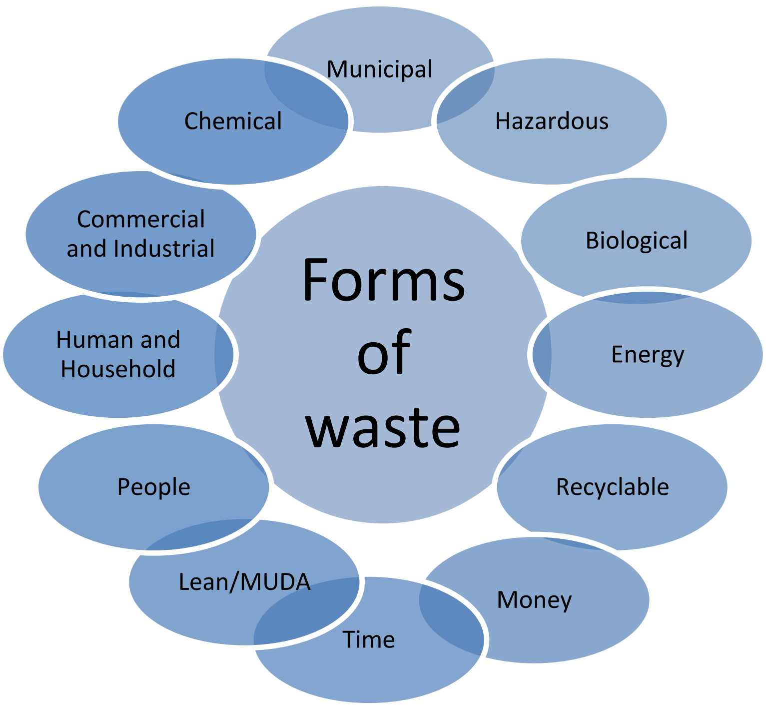


Figure 11: A representative sample of the more common forms of waste (T. Roosen illustration)

3.2 Methods of waste management

It follows then that waste management is the processing, collection and transportation of "non-wanted things, that are perceived to have no purpose or value" and includes any effort to carry out resource recovery procedures to maintain or reduce natural resources. Several broad waste management systems and methodologies will be explored in the following section, which is contrasted with lean management which was discussed in Section 2.1.

3.2.1 ISO 14031: Environmental Performance Evaluation Guidelines (ISO:14031 2000; EPA 2011)

ISO 14000 is a family of standards related to environmental management. They assist an organisation minimise how their operations or processes can negatively affect the environment (i.e. cause adverse changes to air, water, or land). They also seek to comply with applicable laws, regulations, and other environmentally oriented requirements. Thirdly, they seek to continually improve in their processes. The ISO 14000 series is reputedly the most universally used and accepted environmental management system, though there are several others. The ISO 14031 from the ISO family relates to Environmental Performance Evaluation (EPE) and is a management system which aims to assist organisations in identifying their environmental aspects, determining which aspects they will treat as significant, setting criteria for environmental performance and assessing environmental performance against these criteria. This standard uses the Plan-Do-Check-Act business process improvement model which is common to the many standards in the ISO 14000 environmental series (as well as the health and safety, risk and quality ISO standards). A summation of this model (as applied in ISO 14031 EPE) is illustrated in Figure 12.

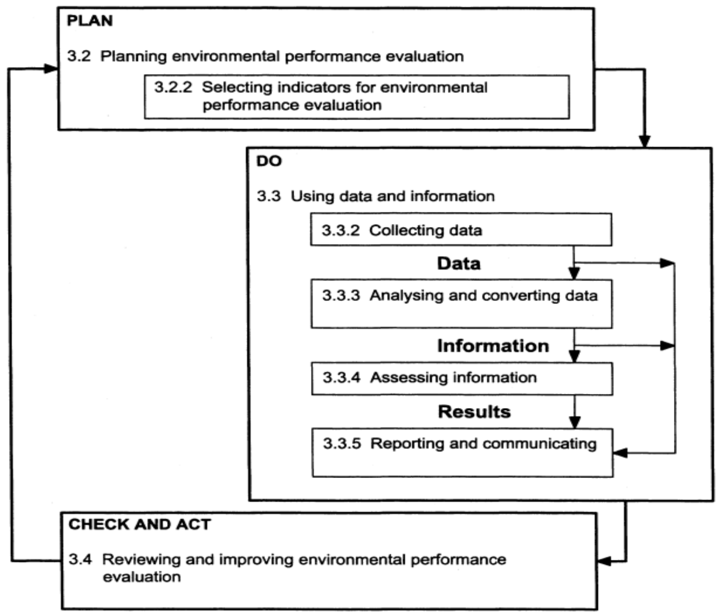


Figure 12: Summary of the Plan-Do-Check-Act business process improvement model applied in Environmental Performance Evaluation guidelines (ISO:14031 2000) .

The EPE standard breaks the environmental assessment system down into four stages: Plan, Do, Check and Act. The first stage 'Plan' incorporates planning the EPE process and selecting the appropriate indicator(s). This may be the most important and relevant part of this particular assessment method with respect to the development of an overall value stream environmental index project. The standard describes Environmental Performance Indicators (EPIs) and Environmental Condition Indicators (ECIs) which provide information about the performance and condition of the environment and is further described in Section 3.3.1. This information is used to help an organisation better understand its impacts or potential impacts on the surrounding environment. The standard further elaborates on measurement indicators including: direct, relative, indexed, aggregated or weighted measures.

The "Do stage" is primarily associated with data acquisition and reporting and is summarised in Figure 13.

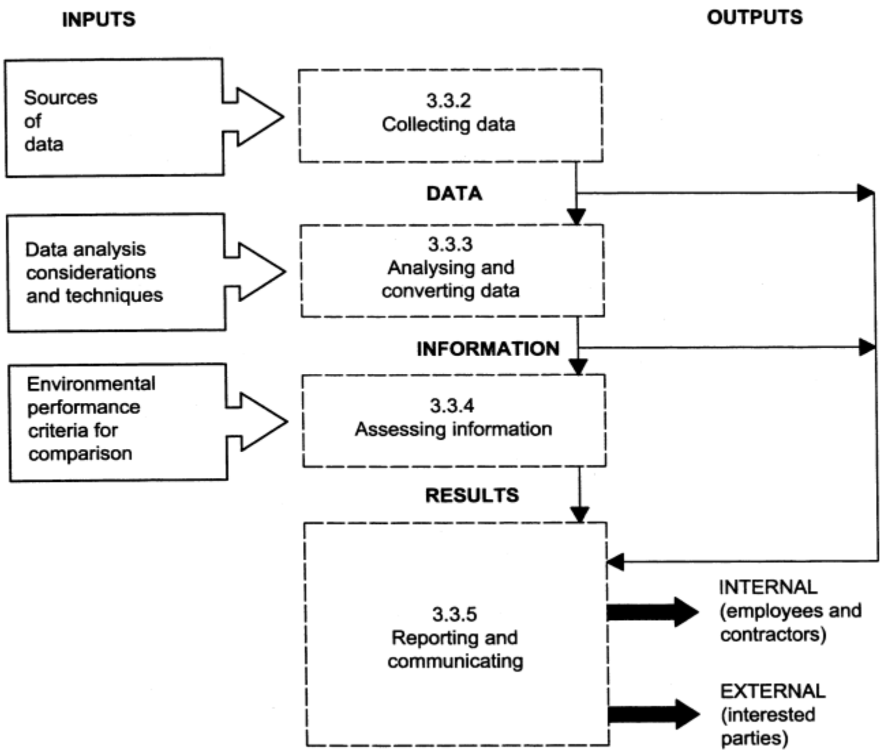


Figure 13: Summary of 'Do' stage "using data and information" for Environmental Performance Evaluation development (ISO:14031 2000).

The final two stages "Check and Act" are part of a continuous improvement tool in which the standard states that the developed EPE should be periodically checked and then reviewed and opportunities for improvements monitored.

3.2.2 Life Cycle Assessment (ISO:14040 2006)

As part of the IS0 14000 family, another approach is found in the ISO 14040 standard entitled Environmental Management – Life Cycle Assessment – Principles and Framework. The principle definition of Life Cycle Assessmen (LCA) is the assemblage and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout the product's life cycle. The LCA model is a more focused approach to waste management than the ISO 14031 waste management guidelines discussed previously. (Figure 14 provides an LCA overview.)

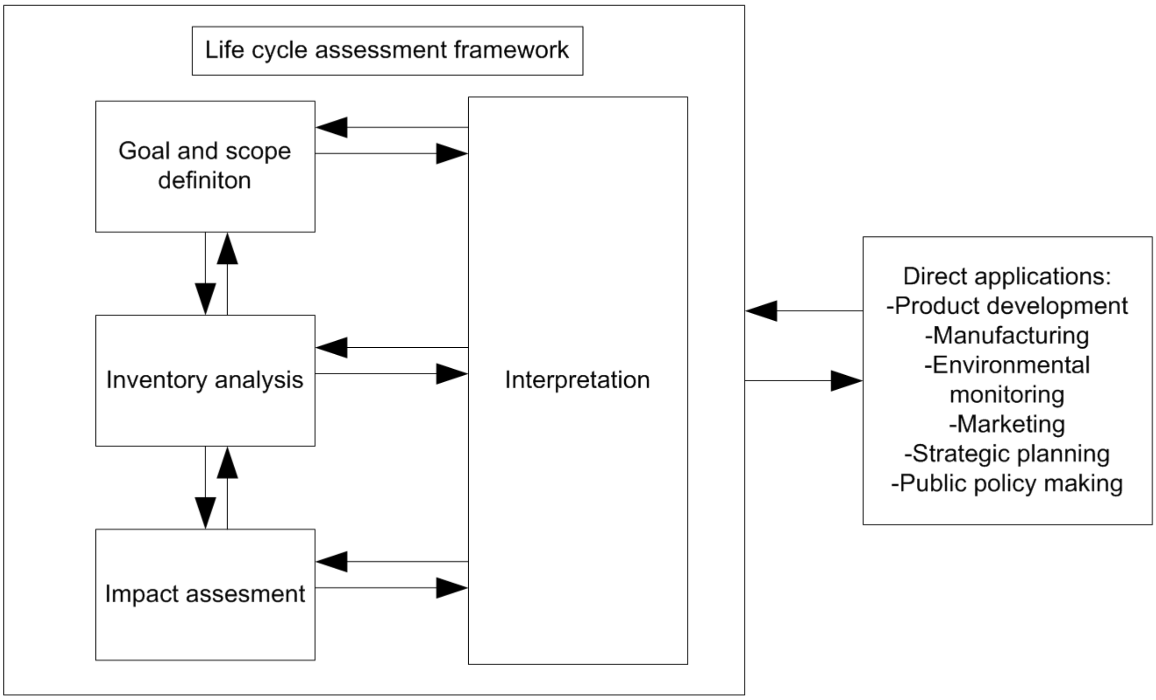


Figure 14: Illustrates the typical phases of a Life Cycle Assessment Framework (ISO:14040 2006).

The LCA model has a series of key features that are crucial for the implementation of any environmental management analysis system and is summarised in the following points.

- The first characteristic of the LCA should be the systematic nature in which the assessment addresses all the environmental aspects of the system from raw material to final deposition.
- The depth and detail of the framework and analysis is allowed to vary and depends on the required extent of the study, defined by the goal, scope and purpose initially defined.
- Data sources, calculations, scope, assumptions and quality of data description should all be included, easily communicated and transparent.
- Confidentiality should be considered when following a LCA analysis.
- LCA should be open to new scientific findings which can be incorporated into the scope and results.

- LCA studies have specific requirements to make comparative assertions that are disclosed to the public.
- There is no single method of actually conducting LCA studies; so organisations must be flexible in terms of adapting the LCA system based on the guidelines suggested in the ISO standard.

Thus, the scope of the study depends on the detailed requirements of the actual situation. ISO 14040 suggests the following items be clearly described and considered when defining the scope: the functions of the product system(s), the functional unit, the product system to be studied along with the product system boundaries, allocation procedures, data requirements, all assumptions and limitations, initial data quality requirements and type / format of the report required for the study.

The system boundary is a crucial element to the scope as it determines which processes and elements of the overall system will be included within the LCA study. Many factors determine the system boundaries, some of which include: intended application of study, the assumptions made cut-off criteria, data and cost constraints and intended audience. The data collection and calculation section should consider both allocation procedures and calculation of energy flows. Life cycle impact assessments (LCIA) are another crucial element to the overall LCA procedure. LCIA should be aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. Finally, the interpretation of the life cycle is where the findings from the inventory analysis and LCIA are combined in order to create an informed recommendation and conclusion with respect to environmental waste management.

3.2.3 Cradle to Cradle Design

Cradle to cradle (C2C) is a methodology that uses biomimicry to compare and analyse the human resource system as a biological organism where materials and resources are modelled as nutrients in a health metabolism. The initial coining of the term was by Walter R. Stahel in the 1970’s, but it wasn’t until a modification of the Life Cycle Assessment occurred which saw the birth of the C2C ideology through the publication of *Cradle to Cradle: Remaking the Way We Make Things* (McDonough and Braungart 2002). The primary theory of the C2C principle is the idea of regenerative design in which every product is produced in a way in which it ensures recyclability of the resource. The overall system has two main components or ‘classes’ of products for which all materials are labelled. The first is ‘biological (or organic) nutrients’ within the system, meaning the material that can be easily reinterred into the natural environment with little to no human intervention. The other term is that of ‘technical nutrients’ in which the material is non-toxic, non-harmful synthetic material (such as plastics or metals) that remain (and is preferentially retained) within the closed loop industrial cycle. The C2C model is very effective in modelling resource flow throughout the manufacturing industry. Braungart and McDonough devised a step-by-step strategy to effectively implement the transition of eco-efficiency into production systems. The five steps are described in the following excerpt (Braungart, McDonough et al. 2007):

- “Free of…” - In the first step, companies investigate their product lines and gain an understanding of the impact of materials used including those substances that are most harmful or dangerous. The removal of these resources is termed “X-substances” which creates greater eco-efficiency and eco-effectiveness.
- “Personal preferences” - At this step, the most undesirable substances have been removed from the system. The next stage is to consider which resources (with natural life cycles) that can be used to replace existing ones. A detailed analysis of the impacts of each material on the environment should result in suitable alternatives.
- “The passive positive list” – In step three, there is a systematic assessment of each component in a product classified according to the toxicity. Products are analysed for their ability to flow between biological and technical nutrients particularly those that reduce this interchange. As a result of this assessment, products can then be constructed classifying each substance according to its “suitability for the biological metabolism”. The passive positive list contains three levels:
    - the X List – substances that must be phased out, such as mutagenic or carcinogenic,
    - the Gray List – problematic substances that are not so urgently in need of phasing out and
    - the P List – the “positive” list, substances actively defined as safe for use.
- “The active positive list” - This fourth step is primarily focused on the optimisation of the “positive” list until each component of the product is positively defined as a biological nutrient or technical nutrient. This is the core of the concept of eco-effective design and seeks to define the product’s ingredients for its positive effects on the world. This differs from step three where the *degree* of optimisation for each product is determined.
- “Reinvention” - The final step in the C2C methodology is to redefine the relationship of the product with the customer focusing on the eco-friendly nature of the product. The objective is for the customer to realise the complete “ownership” of an item which does not have to be viewed as a bad or environmentally damaging paradigm. The ownership thus might be viewed as an interconnection of the economical, social and environmental life cycle system which is the focus of sustainability.

3.2.4 Polluter pays principle

The polluter pays principle, also known as extended producer responsibility (EPR), is specifically the integration of all environmental costs throughout the lifecycle of any product with the market price of that product. It aims to change the waste paradigm from a governmental focus on waste and environmental initiatives. The shift is to corporate or manufacturing entities which produce the waste and thus are also dealing with waste impacts and disposal. The paradigm shift is an elemntary change in responsibility. The responsibility switches from governments cleaning up waste to organisations and producers of manufactured goods absorbing a greater responsibility in the cleaning, storing, recyling and reuse of waste produced. However, the preferential method of waste management would be prevention and minimisation of waste as opposed to disposal and energy recovery as depicted in a typical Waste Hierarchy in Figure 15.

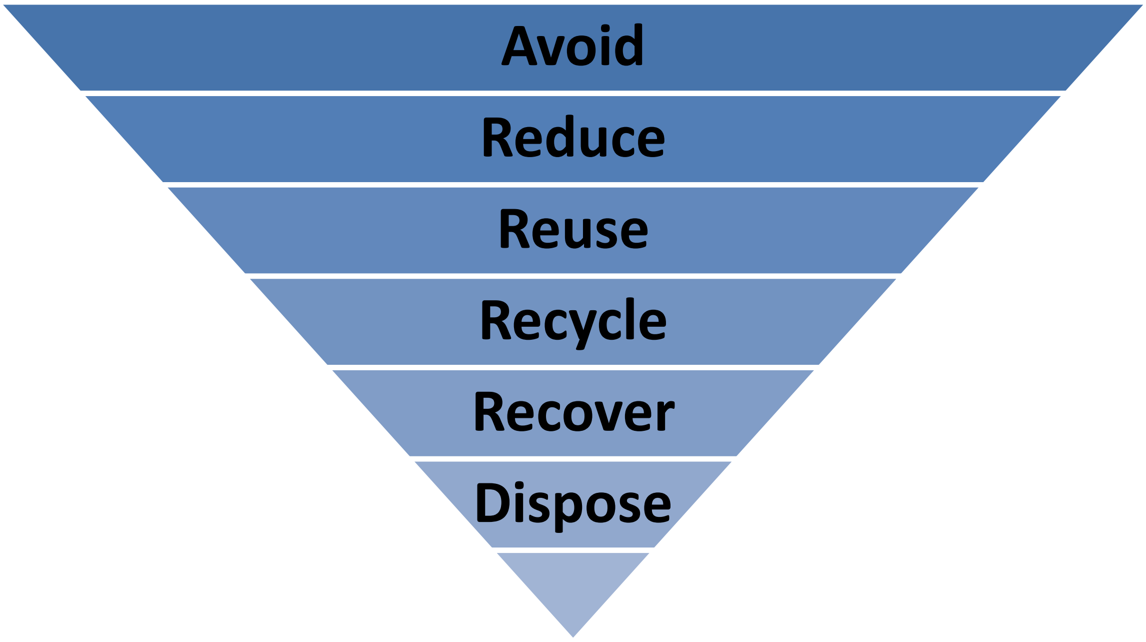


Figure 15: A typical Waste Hierarchy indicating the most favoured to the least favoured (T. Roosen illustration)

Various versions of the waste hierarchy have been used with a variety of different steps and levels. The goal of extended producer responsibility is to decrease overall waste output, as well as increase the likelihood of recyling of waste. Whilst sound in theory and effective in operation, this principle is still not fully utilised due to the high cost to the producer which rolls onto the consumer, as well as the lack of supporting waste management infrastructure.

3.3 Waste management indices

Once an overall waste management framework is determined, it is crucial to then decide on an appropriate index in which specific environmental performance factors can be evaluated. There exists several methods in which the environmental consequences can be measured or evaluated. A series of environmental accounting methods (EAM) will be discussed in greater detail to provide an understanding of common practices and current methods of directly assessing waste amounts. It should be noted that a majority of the indices do not directly account for the principles of a lean manufacturing programme. As illustrated in Figure 16, the focus for most waste management indices is on the more traditional forms of waste and the sampling of indices reflect this.

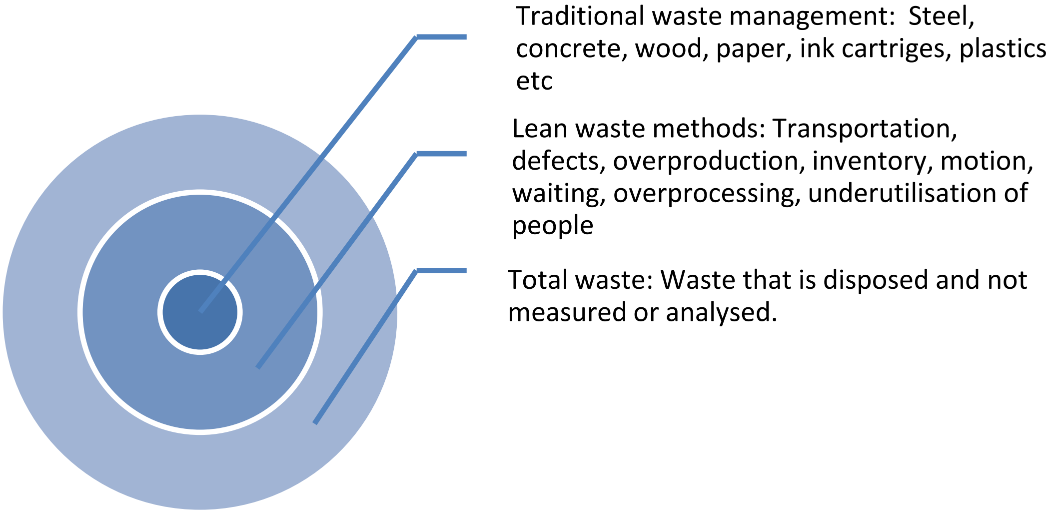


Figure 16: The traditional forms of waste management contrasted with the forms of lean manufacturing wastes in the context of total waste produced. (T. Roosen illustration)

Most indices concentrate only on collecting data for the traditional forms of waste. A review of various indices follows noting advantages and areas lacking with particular focus on possible and relevant Environmental Index Factors (EIF) which are robust.

3.3.1 IS0 14000 Indices

ISO 14031 (reviewed in Section 3.2.1) highlights the development of specific metrics through indicators. The process of choosing the indicator may include choosing from existing indicators or developing new indicators. This international standard describes the two general categories for Environmental Performance Evaluation (EPE) as: Environmental Performance Indicators (EPI) or Environmental Condition Indicators (ECI).

EPI can be further broken down into Operation Performance Indicators (OPI) and Management Performance Indicators (MPI). OPI provide information about the environmental performance of an organisation's operations. MPI are a type of EPI that provides information about a management's efforts to influence the overall environmental performance of the organisation. Environmental Condition Indicators are a third type of indicator that relates to impacts or conditions affecting the environment. Examples of how these three indicators inter-relate is indicated in

Table 2. Methods for MPI and OPI development are further explored in greater detail within the standard.

Table 2: Examples of Performance (Operating and Management) Indicators and Condition Indicators and Metrics (ISO 14031:2000.)

Operating Performance Indicator (OPI)	Management Performance Indicator (MPI)	Environmental Condition Indicator (ECI)
Raw material used per unit of product (kg/unit)	Environmental costs or budget ($/year)	Contaminant concentrations in ambient air ($\mu g/m^3$)
Energy used annually per unit of product (MJ/1000 L product)	Percentage of environmental targets achieved (%)	Frequency of photochemical smog events (#/year)
Energy conserved (MJ)	Number employees trained (% #trained/to be trained)	Contaminant concentration in ground- or surface water (mg/L)
Number of emergency events or unplanned shutdowns (#/year)	Number of audit findings (#)	Change in groundwater level (m)
Hours of preventive maintenance (hours/year)	Number of audit findings addressed (#)	Number of coliform bacteria per liter of potable water
Average fuel consumption of vehicle fleet (L/100 km)	Time spent to correct audit findings (person-hours)	Contaminant concentration in surface soil (mg/kg)
Percentage of product content that can be recycled (%)	Number of environmental incidents (#/year)	Area of contaminated land rehabilitated (hectares/year)
Hazardous waste generated per unit of product (kg/unit)	Time spent responding to environmental incidents (person-hours per year)	Concentration of a contaminant in the tissue of a specific local species ($\mu g/kg$)
Emissions of specific pollutants to air (tonnes CO_2/year)	Number of complaints from public or employees (#/year)	Population of an specific animal species within a defined area ($\#/m^2$)
Noise measured at specific receptor (dB)	Number of fines or violation notices (#/year)	Increase in algae blooms (%)
Wastewater discharged per unit of product (1000 L/unit)	Number of suppliers contacted about environmental management (#/year)	Number of hospital admissions for asthma during smog season (#/year)
Hazardous waste eliminated by pollution prevention (kg/year)	Cost of pollution prevention projects ($/year)	Number of fish deaths in a specific watercourse (#/year)
Number of days air emissions limits were exceeded (days/year)	Management levels with specific environmental responsibilities (#)	Employee blood lead levels (μg/100 mL)

3.3.2 Environmental Protection Agency: lean and environment toolkit (EPA 2011)

The US Environmental Protection Agency (EPA) environmental toolkit provides assistance in developing an environmentally conscious organisation. The most relevant features of the EPA toolkit relate to identification of environmental wastes and an Environmental Value Stream Mapping (EVSM) adaptation as described in Section 2.3. This discussion is primarily interested in the identification of wastes. Initially the toolkit describes links between the ‘seven wastes’ and environmental wastes in identifying critical environmental impacts. The EPA toolkit further explores the ability of targeting environmental waste in an organisation by pursuing five approaches which are:

- Add environmental metrics. This is the most relevant tool with examples of possible environmental performance metrics listed as: Scrap/non product output, material use, hazardous materials use, energy use, water use, air emissions, solid waste and water pollution. These are prime examples of possible metrics that could be added to an EVSM.
- Show management commitment and support.
- Include environmental waste in lean training.
- Make environmental waste visible and simple to eliminate.
- Recognise and reward success.

3.3.3 The use of Environmental Management Accounting (Jasch 2003)

Environmental Management Accounting (EMA) is a combined process that provides a method to translate data from financial accounting, cost accounting and mass balance to improve material efficiency and reduce environmental impacts. The primary focus of EMA is an assessment of the total annual environmental expenditure on emissions' treatment, disposal, environmental protection and management. This methodology excludes costs external to the company. This particular method also focuses more on a comprehensive assessment of direct annual expenditure on emissions treatment, environment protection and management, as well as waste material and energy (e.g. efficiency loss in production). In essence EMA[6] sets up procedures for internal decision-making which include both physical procedures for material and energy consumption, flows and final disposal, and monetary procedures for costs, savings and revenues related to activities with a potential environmental impact.

3.3.4 The total emissions method (King and Lenox 2001)

This particular method seeks to determine (through empirical analysis) evidence of a link between lean production practices and environmental performance. The method explores three main hypotheses. The hypotheses state: (1) that the more an organisation establishes lean principles, the more likely it will adopt formal environmental management systems, (2) the less likely it will generate waste and (3) finally, the lower its emissions will be. The last appears to be the most relevant link to measuring environmental performance of an organisation or manufacturing plant. In other words, an organisation's environmental performance could be defined by the degree it emits toxic pollutants (Hart and Ahuja 1995). This leads to the formulation of an equation to determine the total emissions of a particular plant.

$$Total\ emissions_{it} = ln \sum_{\forall c} w_c e_{cit} \tag{1}$$

[6] As described by United Nations Division for Sustainable Development UNDSD 2001

Where total emissions$_{it}$ is the aggregate emissions of a facility *i* in *t* years; w_c is the toxicity weight for chemical; *c*, and e_{cit} is the pounds of emissions of chemical *c* for facility *i* in year *t*. Unfortunately, this method was found to lack the ability to control for differences in productions and plant size. To overcome this dilemma, King and Lenox developed a relative environmental performance measure. This method uses the standardised residual or deviation between observed and predicted emissions given a facility's size and industry sector. The formulated equations are as follows.

$$\ln(E_{it}) = \propto_{jt} + \beta_{1jt}\ln(S_{it}) + \beta_{2jt}\ln(S_{it})^2 + \epsilon_{jt} \tag{2}$$

$$Relative\ emissions_{it} = \epsilon_{jt} l \sigma_{jt} \tag{3}$$

Where E_{it} is the production emissions for facility *i* in year *t*; S_{it} is the facility size; σ_{jt} is the standard deviation of emissions for sector *j*; and$\propto_{jt}$, β_{1jt} andβ_{2jt} are the estimated coefficients for sector *j* in year *t*. The inclusion of the square term in (2) allows for concave and convex production function. This methodology also delves into environmental management and other methods in which waste is measured, particularly with respect to waste generation and onsite treatment. Their research concluded that lean production and source reduction could allow an organisation to perform well in both quality improvement and environmental performance. Their focus showed new relationships between technology and markets, as well as complimentary implementation of operational practices, such as lean production and green or waste methodologies within the workplace.

3.3.5 Systematic environmental assessment (Brinkley, Karlsson et al. 2000; Salhofer, Wassermann et al. 2007)

The systematic (or strategic) environmental assessment (SEA) incorporates environmental considerations into policies, plans, programmes and strategies of an organisation. Thus the technical, political, and environmental issues are folded into product designs, construction projects or urban planning for example. The SEA method follows a proscribed process flow chart and generates a ranking of design solutions based on their environmental preferability. It begins with defining the goal and scope, as well as primary identification of environmental issues associated with the project. A comprehensive evaluation is conducted by evaluating all design alternatives in a matrix, consisting of their status against each other compared to the previously specified environmental issues as illustrated in Figure 17.

		impact of waste management measures / Factors/Objectives	air pollution	liquid pollutant emission	noise	residues	traffic	utilisation of resources	sensitivity of WMS	costs
environment	human beings	human health, well-being	+	-	+/-		+		+/-	
	flora,fauna	habitats, biodiversity	+/-	+/-			+		+/-	
	Environment	Soil	+/-			+/-				
		Water	+/-	+/-						
		Air	-				+	+/-		
		Climate	-				+	+/-		
	Resources	raw materials						+/-		
		surface area				+/-				
eco	Economy	waste producer								+
		national economy	+/-			+/-			-	
society	Society	utilisation interests	+/-		+/-	+/-	+		+/-	
		landscape and cultural heritage				+/-				
		Autonomy				+/-			+/-	
		job provision								
		convenience	+/-		+/-				+/-	+
		local / regional practicability	+/-		+/-	+/-	+			+

Figure 17: Example of the rating matrix for a waste management system (Salhofer, Wassermann et al. 2007).

In the final phase of the SEA, important features and issues of each design alternative are added as weighted factors to the matrix. A final overall combination of weighted factors determines the final ranking of each design with respect to its environmental impact and suitability.

3.3.6 Volvo – Environmental Priority Strategies (Richards 1994)

As noted in Section 3.2.2, Life Cycle Assessment (LCA) is a core concept in the development of environmentally conscious design and cleaner practices in industry and involves the evaluation of environmental burdens associated with products, processes, services or practices. Volvo, along with the Federation of Swedish Industries, jointly developed an Environmental Priorities Strategies (EPS) system to select appropriate materials to use during construction of its products (Hokerby 1993). This method is based on environmental indices calculated for specific materials. Table 3 shows the factors used to calculate the environmental index.

Table 3: Factors used to calculate the Environmental Index using the Volvo formula

Factor	Meaning
Scope	General impression of the environmental impact
x Distribution	Extent of the affected area
x Frequency	Regularity and intensity of the problem in affected area
x Durability	Permanency of the effect

x Contribution	Significance of 1 kg of the emission of the substance in relation to total effect
x Remediability	Relative cost to reduce the emission by 1kg
= Environmental Index (EI)	-

The Environmental Load Unit (ELU) per kilo of any substance is then found by multiplying the Environmental Index (EI) by the amount of substance released. Many difficulties were found when developing this system. Firstly, there is the potential of too little or too much data included in the parameters giving a false sense of security that the method would provide a clear cut or 'correct' answer. There is also a certain amount of uncertainty when dealing with the information required for an environmental impact / waste analysis. The Environmental Priorities Strategies is however a successful tool for providing a sensitivity analysis – measuring what changes in environmental impacts would change the ELU calculated. This allows organisations to compare one process (or the environmental impact of processes) to another to improve company decision making.

3.3.7 Carbon footprint, greenhouse gasses equivalence and toxicity

Another possible cumulative measurement for waste measurement is the use of a 'carbon footprint' analysis in which waste of a very specific form can be aggregated and measured. The 'carbon footprint' analysis is a method in which the total emission of greenhouse gasses (GHG) is estimated in terms of the carbon equivalence (tCO_2e-tonnes of carbon dioxide equivalent or grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh)) from a specific product. The measurement is taken across a product's life cycle from raw materials used in manufacturing to the disposal of the final product. Its purpose is to measure the individual gas emissions from each activity within a supply chain process and framework and attribute these to each output product (Wiedmann and Minx 2008). A carbon footprint, in other words, is a measure of the total amount of greenhouse gas (GHG) emissions (e.g. carbon dioxide, methane, nitrous oxide, hydoflurocarbons, petroflurocarbons, sulphur hexafluoride, ozone). These GHG emissions are either directly or indirectly caused by an activity or they are accumulated over the life stages of a product.

Toxicity was another possible measure of environmental impact, particularly the impact of a set process with respect to human health. Initial investigation of the use of toxicity as a potential Environmental Impact Factor (EIF), particularly LD_{50}, was discarded due to the high degree in variability of data available for any substance measured. High use of estimated data along with large uncertainties and safety factors did not promote the use of this particular EIF as a contribution to the creation of an Environmental Impact Index (EII).

3.3.8 Global Reporting Initiative

The Global Report Initiative (GRI 2006) promotes economic, environmental and social sustainability. GRI provides companies and organisations with a sustainability reporting framework. The framework includes identification of a variety of aspects oriented towards long term sustainability for the traditional economic, environmental, and social categories. Within the environmental dimension is a section with a number of aspects highlighted concerning emissions, effluents and waste. Both core and additional performance indicators are shown in Figure 18.

ASPECT: EMISSIONS, EFFLUENTS, AND WASTE

- CORE **EN16** Total direct and indirect greenhouse gas emissions by weight.
- CORE **EN17** Other relevant indirect greenhouse gas emissions by weight.
- ADD **EN18** Initiatives to reduce greenhouse gas emissions and reductions achieved.
- CORE **EN19** Emissions of ozone-depleting substances by weight.
- CORE **EN20** NO, SO, and other significant air emissions by type and weight.
- CORE **EN21** Total water discharge by quality and destination.

ASPECT: EMISSIONS, EFFLUENTS, AND WASTE (CONTINUED)

- CORE **EN22** Total weight of waste by type and disposal method.
- CORE **EN23** Total number and volume of significant spills.
- ADD **EN24** Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally.
- ADD **EN25** Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the reporting organization's discharges of water and runoff.

Figure 18: Excerpt from the Global Reporting Initiative framework for Environment[7].

Other performance indicators of the GRI (Environment) include the aspects of: materials, energy, water and biodiversity yielding a total of 30 performance indicators. The GRI has become a widely used methodology for companies to measure and report on their sustainability practices with specific measurements identified.

[7] Extract from G3 Sustainability Reporting Guidelines, sourced from GRI website resource library database (1 December 2012)

3.3.9 Lean waste measurement and custom scales

While all the previous measurements and indices have had considerable focus on the traditional aspects of waste, the final waste measurement method under consideration is the use of lean manufacturing tools to reduce waste. As noted, lean manufacturing focuses on the reduction of the more abstract forms of wastes defined as 'Muda'. Further, Muda includes eight forms of production process waste (seven plus an added factor). This is well beyond the traditional concepts of waste. The advantage of including all wastes, traditional and lean, is the creation of a robust system for effective and efficient production that takes into account a wider spectrum of variables. The specific measures used to equate or quantify these forms of waste and include them with the VSM process are the primary focus of this paper.

Thus, this application will include the use of VSMs to evaluate the time associated with these processes of waste identification, reduction and measurement. Finally, it will also include the calculation of the more traditional aspects of *environmental* waste such as water, energy or hazardous material from a series of processes using the VSM as a tool to reduce these waste streams.

The final index representation to be discussed is an agglomerated scale that could be developed to directly represent the environmental impact (ENI) of interest. A customizable scale would allow the end user to tailor the index to suit the process and allow a filtered type approach to measuring the various environmental impacts. An example of a custom index could be to multiply the toxicity and volume of waste together to get a resulting number that would indicate the ENI of that process. Any number of elements could then be added to the scale, such as cost of remediation, carbon amount and energy usage for example. The final number for each process would then be compared to determine which process, according to the pre-determined index, has the greatest ENI. The ability to create multiple permutations using a custom scale is very conducive to a flexible ENI index representation.

The idea of using a direct representative consequence scale is a simplistic evolution of the custom scale. This purposed index would use a predefined consequence scale to judge the ENI and consequence of each process. The consequence in this sense would be a far more subjective measure that would have to be identified at the start of each VSM and relate the Pratt and Whitney strategic vision to what wastes are deemed acceptable to society and those considered not acceptable. An example of a customised consequence scale would be to create a scale from negative 10 to positive 10. This scale would then be divided by zones ranging from not acceptable through undesirable, neutral, acceptable and finally desirable activities. Each process would then be ranked according to its desirability with respect to social acceptance. This system would rely on individual judgment and could be far more subjective to personal motivations compared to a standard objective data based index. However, it would likely reflect many aspects of the Pratt and Whitney policies, practices and vision.

3.4 Impacts: consequences and costs of waste

Several key consequences are a direct result of the lack of effective waste management. The waste consequences were based loosely on the PESTLE analysis and sustainability models specifically the categories of: Environmental, Strategic, Economic and Social. (Note that typical sustainability models use the three pronged approach of environment, economic and social impacts. Strategic was added for the purposes of this paper.) Consequences for both the solid form of production and process waste, as well as the lean waste aspects will be explored briefly in the following sections.

3.4.1 Environmental

The most direct and recognisable impact of poor waste management is the degradation of the environment due to excessive pollution and the secondary effects of global climate change. Climate change refers to any significant change in the measurement of climate including temperature, precipitation, barometric pressure or wind lasting for an extended period. (Global warming was the initial description noted relative to the extensive warming trends on the planet.) Science has produced a large body of evidence correlating increasing human activity (anthropogenic activity) to global climate changes. The generation of all forms of waste (traditional and non-traditional) is a part of those activities. The other primary environmental impact is the reduction of integrity of the remaining natural habitats with respect to the remaining forest reserves, oceans and fresh water reserves. These consequences are directly related to produced emissions, natural waste and resource mismanagement.

3.4.2 Strategic

The strategic and political consequence of waste—both in terms of the environmental material waste and in terms of the lean waste principles—is of significant importance to an organisation’s growth and public image. The term ‘waste’ in the context of this paper can thus be redefined as the Non-Value Added (NVA) activities that absorb resources. This paper is primarily concerned with the importance of including lean waste consequences for any environmental indexing system. The term lean in this case represents the tools, primarily VSM, that reduce wasted time, money, NVA activities and increase a company’s performance and efficiency through reduction of Muda. The importance and therefore consequence of a company adopting the lean production waste management system is a multi-dimension result in which not only are costs often reduced; but a company’s performance also increases as a result. These wasteful activities lengthen lead times, create extra movements of products and equipment and can create wasteful excess inventory.

As distance between producers and consumers increases, the price of fuel, price of goods and price of services increases. Thus, producers come under increasing pressure to reduce costs and resource use in any way possible. The consequence of this is to change the production paradigm from one of mass production and over-consumption with large unused inventories to one of lean production management where continuous improvement initiatives seek to reduce NVA wastes. This reduction of resource consumption and streamlining of process performance also results in the reduction of material consumption, which in turn reduces the emissions, environmental damage and degradation required to create the final product. The key to applying any lean process improvement is to focus on Value-Added (VA) operations and work to eliminate waste in the lean production sense of the word.

3.4.3 Economic

The primary economic result from lean production management is reduction of overheads and one of the most important diminutions of costs is through reducing the eight wastes. Elimination of waste using lean manufacturing principles improves economic performance by reducing consumables and overall resource use. This is of particular importance when competing with larger companies or organisations which are closer to the consumer. By reducing production, manufacturing or remanufacturing time, there is justification for the possible increase in costs due to transportation. In terms of the more notable and common solid production wastes (such as water, material or hazardous material) organisations take a different approach to dealing with the problem. Due to the common paradigm of governments taking responsibility of municipal waste management from most manufacturers, a 'high cost low benefit' waste disposal approach is used. Accounting for this waste may lead to a more efficient and environmentally friendly waste prevention or minimisation approach that could be implemented at the producer level before the waste is even generated. While this approach is generally preferred by the manufacturers, it is often ignored when the problem becomes someone else's and the costs associated with recycling or waste prevention are neglected, thus maximising return. However, leaving solid waste management up to governing bodies also results in an increase in costs to dump or manage the waste and finally a decrease in the value of land surrounding waste disposal, landfills or management centres due to social rejection, which may have an effect on corporate social responsibility.

3.4.4 Social

Historically, lean and solid waste is generally regarded as negative and rarely viewed as a resource. The social rejection of solid waste is exemplified with most landfills and waste disposal systems located away from populated areas. Waste is socially seen as something 'others should have to deal with' and disassociated from both the producers' and consumers' purview. This leads to a rejection of social responsibility with respect to the proper management and prevention of waste. Recently this paradigm has begun to shift with some producers and consumers realising the need for a social awareness of waste and actively promoting biodegradable or environmentally friendly products. The social aspect of lean waste management and the resulting consequence is primarily related to the change in an organisation's culture associated with lean implementation. Lean waste reduction is an inherent culture within an organisation that relies on employees actively and continuously improving and using lean techniques to achieve a more efficient end result or process. This often results in an organisation examining and realigning its organisational culture to firmly establish a progressive and lean management enterprise which could include its traditional wastes.

3.4.5 Overall

Overall, as demonstrated in this chapter, there are strong motivators to develop a fully formed environmental index that accounts for both the traditional, as well as the lean practices used in servicing industry and manufacturing. However, as there is no fully developed environmental index in place, this will require change management within an organisation.

4 Change management needed to implement a new lean manufacturing tool

Overview

The initiation of any improvement in production processes will necessarily involves change. A theme in this paper is to successfully integrate environmental waste reduction into lean management practices. Development of a new environmental index to reduce waste will thus involve change. While it is possible to create a new method that achieves this, the question with all implementation is: How effective is the change in the organisation? Or, how can the innovation of a new environmental index be guaranteed to be used in the industrial setting? Typically this requires managing the change, which is the focus of this chapter. Change management principles help facilitate the environmental VSM changes in actual practice.

This chapter reviews change management methods as applied to engineering and lean manufacturing and contains six sections. The first section is a detailed literature review of change management with a focus on the development of methods to effectively create change management opportunities. The second section includes an overview of strategic alignment and how change arises. The third section discusses methods for successful implementation of change initiatives and includes and evaluation of change literature. The fourth section reviews the resistance to change, the role of culture and consequences of change. Gaps in knowledge are explored. The fifth section contains an investigation of the paradigm of lean manufacturing change. The benefits and detriments of lean change initiatives are examined, followed by an examination of the barriers to the lean change concept. The sixth section explores conditions favourable to change to better understand and avoid the limitations of implementing new lean manufacturing tools, such as an environmental measurement index integrated with VSM. Using a developed model for successful change management, the alignment for successful implementation of a new engineering system or process is set out followed by a summary of the chapter.

4.1 Change management literature review

4.1.1 What it means to change and what is changing

The primary meaning of the word change is to transform or convert. It includes the concept that there will be a difference from the original. In the context of engineering change management, 'change' means to transform a system or set of operations from an original state into a more efficient future state. For example, change management is the ability of an organisation to help employees within a company accept and embrace the implementation of a new piece of technology or a new system. Change management often focuses on the minimising of change impacts on workers. This incorporates the goal of reducing the distractions of change throughout the working environment and maintaining a high level of efficiency throughout the implementation process. Within the engineering, manufacturing and management context, there are many forms of change. Some of these change types include:

- Operational, system, process or methodology change
- Attitude and behavioural change
- Changes in culture
- Legislative and governmental change
- Organisational strategic purpose change
- Technological advancement and change in tools
- Change of mission and or management
- Change of skills
- Change in communication levels, frequency and effectiveness
- Engineering change management (product redesign and optimisation)
- Change of organisational structure and hierarchy
- Improvement of internal efficiency and profitability
- Changes in entering a new market
- New product or services changes.

If these changes are grouped in categories, they can be depicted in a series of banding categories as illustrated in Figure 19.

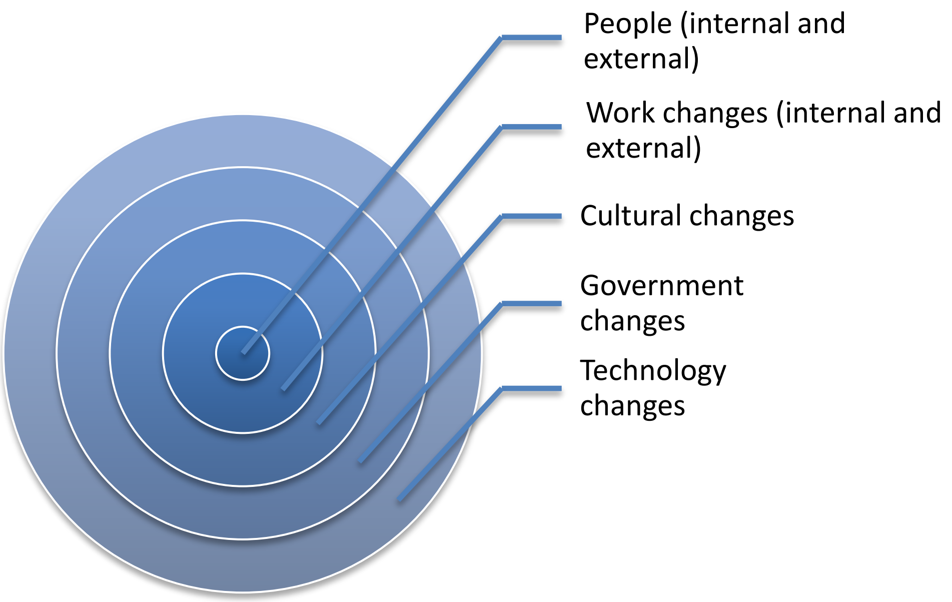


Figure 19: The type of changes that can occur falls into broad banding categories (T. Roosen illustration)

However, the definitions of change vary widely. The categories above can also be elevated to even larger global changes such as climate change. These changes can occur singly or more often, multiple changes will occur. One straightforward definition describes change as the utilisation of a set structure to control an organisational change (Kotter 2007). The term 'to change' can further be defined as an adaptation to current operations to improve the performance or efficiency of a set system, process or skill. Though primarily meant to improve performance, change can also include the deterioration of efficiency due to poorly applied, designed or implemented change methodologies. The focus of this chapter will be on the change management in engineering organisations, specifically the manufacture / remanufacture industry with the associated change management implementation. This chapter will not examine Engineering Change Management which investigates specifically the principles of new product development and design solution optimisation.

In acknowledging 'what is changing', faster communication, technological advancements, improved production capabilities and a continuing refocus of core company policies have all contributed to changes which have a decreased product development time from initial design through to final manufacture. In turn, this has the follow-on effect of increased customer expectations. The ability to collate, compare and gather information from the internet (in minutes compared to the days) is one example of the increase of speed in business processes and systems (Grebe J.C 2001). 'What is changing' clearly ranges from the lowest level of manufacturing tools and systems up to the managerial operational procedures of group leaders and Chief Executive Officers. In essence, it is as the Greeks said long ago, "Nothing is permanent except change" (Heraclitus).

4.2 Strategic alignment and how change arises

Alignment is the adjustment of an object in relation to other objects. This arrangement leads to optimising the position or relationship between the objects or parts. With strategic alignment, the goal is to improve performance results and gain a competitive advantage. Engineering services and manufacturing facilities around the world experience the need for change on a continual basis due to a wide variety of influences on the organisation. This results in a transformation of strategic alignment (internal and external). This need for change arises both externally *and* internally due to a myriad of factors ranging from economic pressures, technological advances to socio-political factors. It is therefore important to identify specific factors that contribute to the need for change. There are hundreds of factors that necessitate the need for change. Some of the more prevalent themes are explored starting with external influences followed by internal pressures (Navarre and Schaan 1987; David 1996; Grebe J.C 2001; Balogun and Jenkins 2003).

4.2.1 External business environment

The external business environment is a large external driving force that tends to either constrain business choices or improvement strategies or provide opportunities when developing potential business avenues or possible future bids / projects (Grebe J.C 2001). The first most easily identifiable challenge that results in the need for an organisational shift in strategic alignment and process change is the ever-evolving competition within the global and local markets. Competition can yield cooperation in order to achieve market domination or present serious risk due to over-extended product lines where production capacity does not keep up with demand. The moment a weakness is shown within an organisation, competitors will readily seek to exploit the fault to maximise their gains and company growth (usually at some other organisation, activity or person's expense). The exploitation of weakness is exemplified throughout the manufacturing industry in which companies perpetually seek to gain 'the edge' to provide a cheaper, better, stronger product, thereby gathering a greater customer base.

4.2.2 Customer demands

The transformation of customer demands, expectations and requirements is one of the primary forces that affect change. The pressure and expectations from clients historically comes in the form of providing a stronger, cheaper, new (etc) product to customers. A growing trend of new customer expectations (e.g. due to increased concern for the environment) is the ability for organisations to provide not just a cheap and reliable product, but also a product that is concerned with its environmental impact, carbon footprint and incorporates some form of sustainability management. An organisation that pursues and maintains a green image can often increase prices on its products, while still edging out competition, as well as garner public support and even government acknowledgement.

4.2.3 New laws and regulations

New laws and regulations that are updated, modified or replaced are a constant source of change for any organisation. For example, environmental sustainability and low carbon emission targets are another common theme prevalent in recent governmental regulations regarding the manufacturing process and products. Larger firms worldwide have been increasingly tasked by local authorities to reduce emissions, sustainably manage production or pay carbon offset taxes in efforts to curb the environmental impact of greenhouse gas emissions. Aside from environmental performance, laws and regulations can also drive change when firms deploy a product in a new country. Often regulations will require a change in the product to adhere to international or national standards of health and safety, thereby changing the manufacturing process through re-tooling or re-design.

4.2.4 Economic climate

The current economic climate (both locally and globally) can drive strategic realignment and the need for change. Economic climate is arguably the largest driving force for change within any organisation. An example is the Global Financial Crisis (GFC) and the subsequent bailout of companies, such as General Motors the current largest car manufacturing firm in the world. Another example is the economic wealth and rampant expansion of Dubai and Abu Dhabi in 1995 – 2009. Changes to the tax structure and subsidies in the United Arab Emirates led to a massive stimulation of growth in the constructions sector as seen in Figure 20. This led to a large increase in both mechanical and civil engineering projects resulting in fundamental shifts in the way products and services were supplied, managed and produced in the region.

Figure 20: Changes in growth stimulation in Dubai as depicted by construction along Sheik Zayed from 1991 to 2009 (Photos: Courtesy of Timothy Roosen)

This demonstrates the need for manufacturing companies to change and adapt as swiftly and efficiently as possible. This ability to adapt to changing economic circumstances has led to the success and failure of many organisations throughout the world through the use of various change management models and methodologies.

4.2.5 Financial strength

Capital, growth, assets and financial strength are all examples of the internal monetary attributes that lead to subsequent growth or decline of an organisation. These internal factors relate the needs, attributes and desired future state of an organisation resulting in subsequent changes in strategic alignment. Internal financial strength is certainly the fundamental support or backbone of a company's ability to change, adapt and survive in the competitive manufacturing marketplace.

4.2.6 Organisational culture

Organisational culture (in the field of organisational studies and management) describes the psychology, attitudes, experiences, beliefs and values (personal and cultural values) of an organisation. Organisational culture is arguably the most vital element driving organisational change management through any firm. Without proper examination, preparation and use of the company's fundamental culture currently in place (or instalment of organisational culture if lacking), implemented changes will almost always fail.. Culture is the crucial foundation for implementation of change management. The culture outlook can help employees accept and embrace changes to the current business environment. Resistance to change often comes with neglect of a company's culture. The cultural element of change management is also closely linked to the management of employees' skills and morale. The modification and encouragement of skills, continuous improvement, pride in workmanship and attention to morale (to name a few) are all linked to the internal organisational culture.

4.2.7 Product line and markets

Examination of the current product line, current target market and possible target markets are required internal influences on the structure and strategic alignment of a company. A company often needs to realign the current target markets to possible future markets in an effort to sustain growth and provide a secure future working environment. This realignment may result in a subsequent change of product and services thereby creating further opportunities for the application of change management methodologies. Target market planning and acquisition requires careful internal management, as well as risk mitigation and opportunity assessments. A relatively new internal force affecting change throughout organisations is the diversification and internationalisation of project teams which develop the product lines and markets. With increases in communication, global knowledge, travel and population movement, the structure of organisations is changing from a monoculture (primarily singular ethnicity employees) to multicultural organisations that require a substantial amount of change management to ensure a smooth transition and functionality for all its varied employees involved in different product lines and markets. The varied workforce behaviour, ethnicity and language often found throughout modern organisations presents real challenges in terms of unifying internal change management procedures and strategic cultural alignment common to everyone. Figure 21 provides a snapshot of these change factors depicting a negative or positive approach. These change factors can be external or internal but their impact can change according to their use within the organisation.

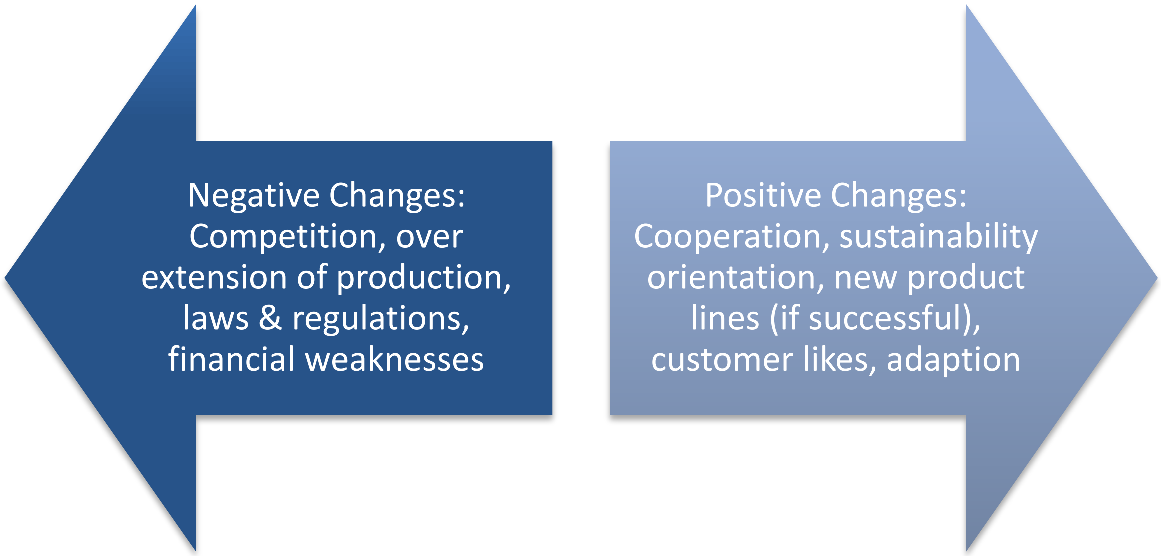


Figure 21: A snapshot of change factors which can be negative or positive. Their impact can change quickly or over time relative to their use within the organisation. (T. Roosen illustration)

4.3 Methods of successful implementation of change initiatives

4.3.1 The change management model

There are a wide range of change models that encompass the various methods of change management. These change management models range from process/phase models, psychological/emotional models to planned vs. evolutionary models. Just as change management theory and applications vary dramatically in both form and function, there is varying structural differences between various methods and subsequently the models used for the change process. For example, change methods vary from phase models, emotional models, and branded approaches for specific organisations. There is varying processes for the number of sequences (such as Kotters' eight steps) (Kotter 2007), fourteen principles, five factors of change (Chu) and many other steps, keys principles or approaches. A frequent variant to the models depends on which personnel will implement the change (and who is affected by it). Another variable is the direction of the change e.g. from top down to bottom up. In addition, the change implementation can vary as to time to accomplish which directly impacts on the budget. The outcome can also have different results. A summary of the variables in the landscape of change management was created and is shown in Figure 22. This summarises the variables into the categories of: structure, process, personnel, direction, time / budget, outcomes.

VARIABLES IN THE CHANGE MANAGEMENT IMPLEMENTATION

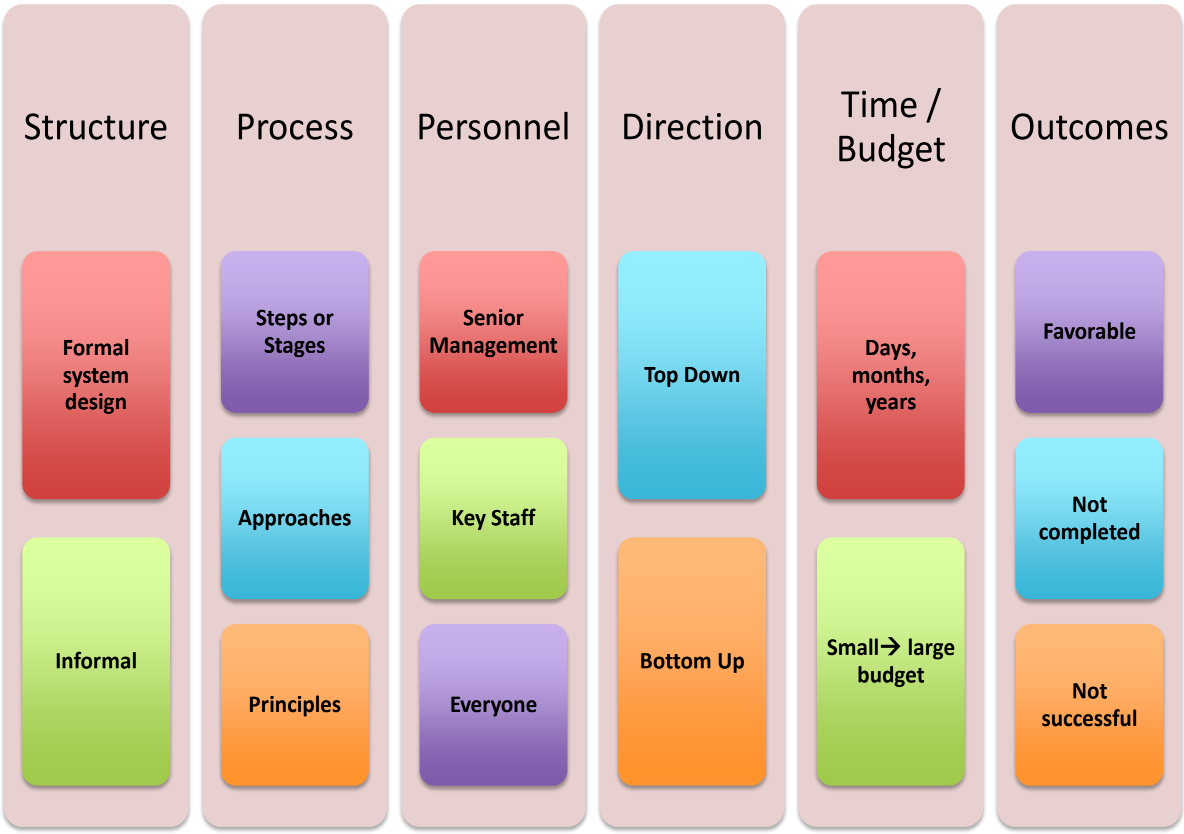


Figure 22: Change management implementation variables (T. Roosen illustration)

Two historically recognised and debated change management models are: the evolutionary (adaptive) model and the teleological (scientific/planned change) paradigms (Carnall 1995; Kezar 2001; Morgan 2006). Briefly the evolutionary / adaptive model evolves on progressive mutation often due to outside influences. The teleological / scientific model is a step-by-step approach where a process brings about change. A third change model is the political model which is as prevalent but is historically recognised as a combination of both the evolutionary and teleological models (Van de Ven and Poole 1995). Further widening of the spectrum of change models resulted in the inclusion of social cognition, cultural and emotional change management models. Early paradigms (also subject to change) were expanded to include different theories, adaptions and modifications ranging from social evolution, biological, life cycle and adaptive systems to paradigm reframing models. In overviewing all these models and their variations, a diagram of the suggested interrelationship between the change models is shown in Figure 23. The fundamental models of evolutionary (adaptive), planning (scientific method), political, social cognition, cultural and emotional models will be further examined to determine benefits, criticism, primary change concept and key outcomes, as well as general approaches to change.

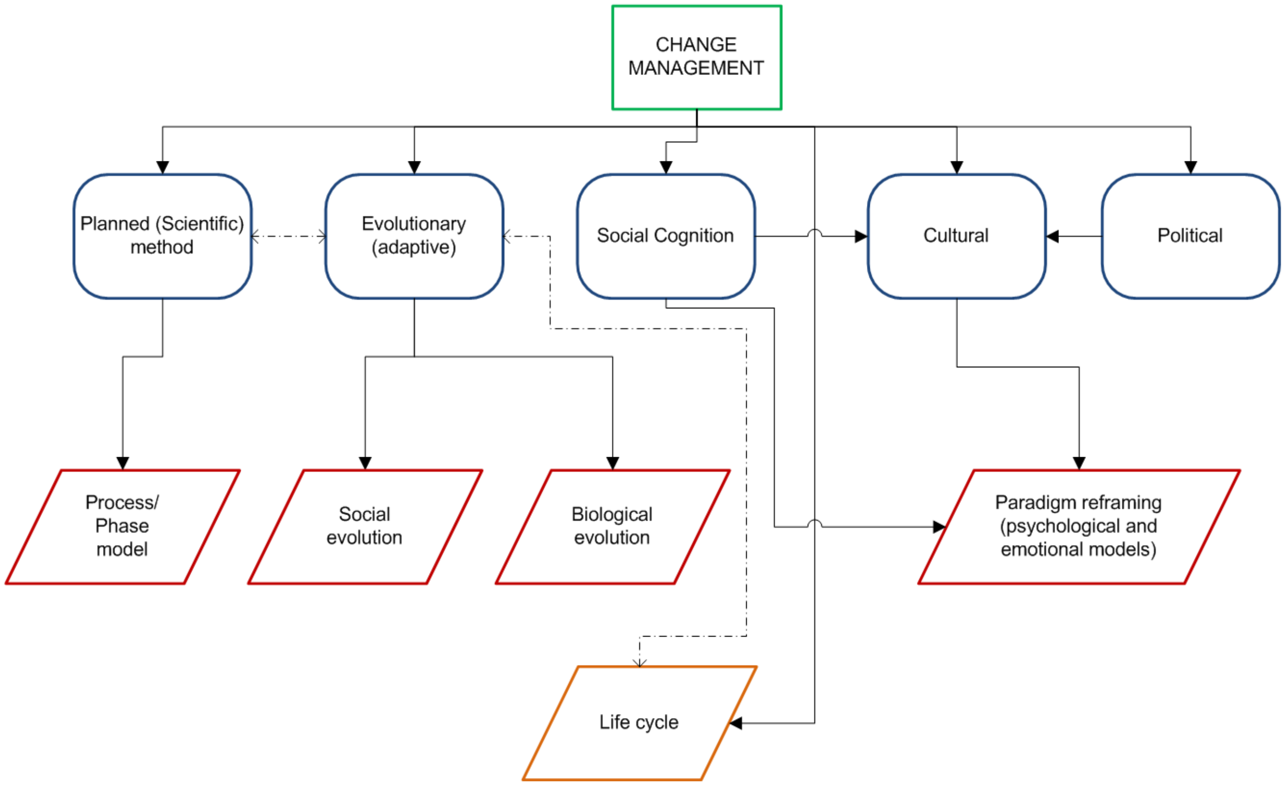


Figure 23: Created illustration of interrelationship of change management models. Solid lines show a direct relation between models whilst dotted lines reflect that models only share some aspects. (T. Roosen illustration)

As noted, evolutionary change models focus on the biological nature of change as it evolves in a slow focused approach, following progressive mutations which are progressively shaped by outside influences (Morgan 2006). The teleological (planned/scientific model) is a prevalent model often used within modern corporate governance especially by organisations which focus on downward driving organisational management. The teleological model is viewed as a rational, linear, and step-by-step or phase-driven design where a set process brings about change. Social cognition is a more human factors orientated approach to the modelling of change management. The key factors of social cognition include the ability of people to interpret their environment and change processes and the shaping of processes by the leaders through interpretation and individualism within the organisation (Kezar 2001). The political change models explore the use of coalition forces of dominant theories and inherent power cultures, along with a focus on individuals throughout the organisation. The emotional change management model uses inherent human emotions to achieve an end result or successful change. The emotional model is more a descriptive chronicle of human response to environmental changes. For example, the stages of denial and isolation, anger, bargaining, depression and finally acceptance represent emotional changes. Another common emotional example is the Exit, Voice, Loyalty or Neglect (EVLN) paradigm which categorises the four primary active or passive human responses to change implementation. The cultural model is an amalgamation of both political and social cognition models (Kezar 2001; Morgan 2006). Change through the cultural model is often chaotic, non linear, socially driven, with specific integration of individualism, beliefs, feelings, myths and rituals of an organisation.

4.3.2 Evaluation of manufacturing change literature

From this discussion it is clear that many views are expressed on the appropriate method to implement change management. Each change management method or approach has its similarities, limitations and advantages, as well as proponents and opponents as to its value. However, through extensive research (Grebe J.C 2001; Chu 2003; Kotter 2007; Kotter 2009), a common set of procedures for progress in change management systems has been created and surmised as shown in Figure 24.

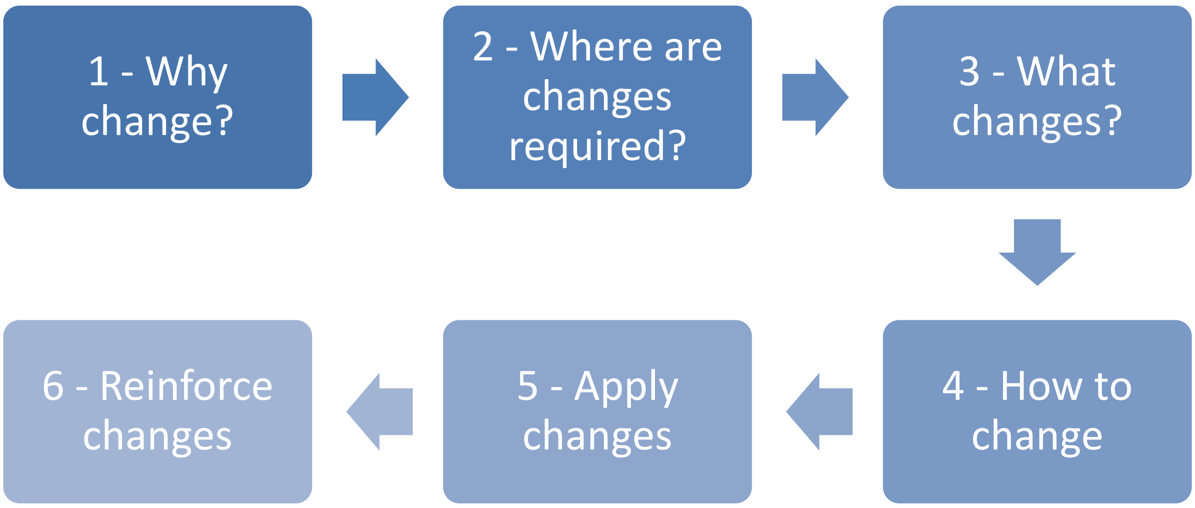


Figure 24: Common change stages found throughout literature (T. Roosen illustration)

The six stages which have been identified as defining the general or universal steps used for many change management theories are described as follows. The initial stage of common change management approaches and methods is to determine 'why' the need for change has arisen. Examination of the organisational structure, purpose, common problems, and deficiencies are routinely used to determine why there is a need for change. Greater knowledge of the change is required so that a commitment to the change can be established. The commitment to creating the change is a key initiating factor that drives the change throughout the organisational. Focusing on 'why change' is required to effectively set the groundwork for the change. A strong need and strong commitment is cited as mandatory for successful change.

The second stage is an in-depth description and evaluation of 'where' change is required. This stage differs to discovering 'why' the change is required by identifying the boundaries for the change process. Defining 'where' allows the team or organisation to focus on the transformation for a precise location, process or event.

The third stage is to further discuss and define ‘what’ needs to change and ‘what’ will be the primary results of the change. Investigation of what the transformation will do is a crucial step to inform and educate the group or organisation and allow them to readjust, as well as familiarise themselves with the exact change result. If done well, this stage reduces the unknown and unfamiliar of the purposed change result throughout the organisation.

After analysis of ‘what’ the change will do and ‘what’ change is required, exploration of ‘how’ to bring about the change is stage four. Some approaches suggest this is best done through top down leadership pushing change through the organisation, as well as leading by example. A paradigm shift of this approach is creating change from the bottom of the organisation. In this tactic, workers are empowered and drive change upwards. When a significant number of people in the organisation participate in the change, it creates a sense of ownership throughout the organisation. Ownership of the process is a psychological shift in which individuals personally feel responsible in bringing about the change, thus allowing a collective to work more cohesively, powerfully, and robustly in realising the change result.

The fifth step is ‘applying’ the change. Once the definition and action for change has been decided, implementation naturally follows. This is the defining stage in the change management process. While simplistic in idea, it is often difficult in execution if the groundwork has not been successfully accomplished. The work and effort that goes into the ‘why, where, what and how’ approach often correlates to the effectiveness of the applied change result. Finally, as a continuous improvement and management technique, the concluding sixth stage is to ‘reinforce’ the change. Greater reinforcement is often required when the previously defined common elements are not carried out thoroughly. Reinforcement comes in many forms such as the analysis of efficiencies before and after change or examined continuously throughout the use of the change process.

4.3.3 Developing changing management model for the application

After reviewing multiple models, methods and approaches to engineering change management, several common themes were found which consistently made the difference between a successful and unsuccessful change management programme. From this review, a more focused model for educating practitioners in industry was created using these three critical pillars to demonstrate what has found to be effective in providing a solid foundation for effective change. The three key facets of the developed model are: employing the organisation’s culture, effective communication (and subsequent education); and finally a commitment to the change process with participation at all levels. This is depicted using a simple three-legged stool illustration as shown in Figure 25. This model graphically reflects the importance of ensuring equal portions of culture, communication, commitment to bring about successful change. These three aspects can be described as the key elements of the stool or ‘pillars of successful change management’. For example, if the organisational culture cannot be effectively used (due to a pre-existing negative culture or a low level of participation), the plane of successful change management tilts as a result of the lack a specific pillar support. To make up for a decrease in one aspect, the other support members must be used in excess. If there is a total deficiency of any one aspect, the 'stool' becomes broken signifying a failed change process.

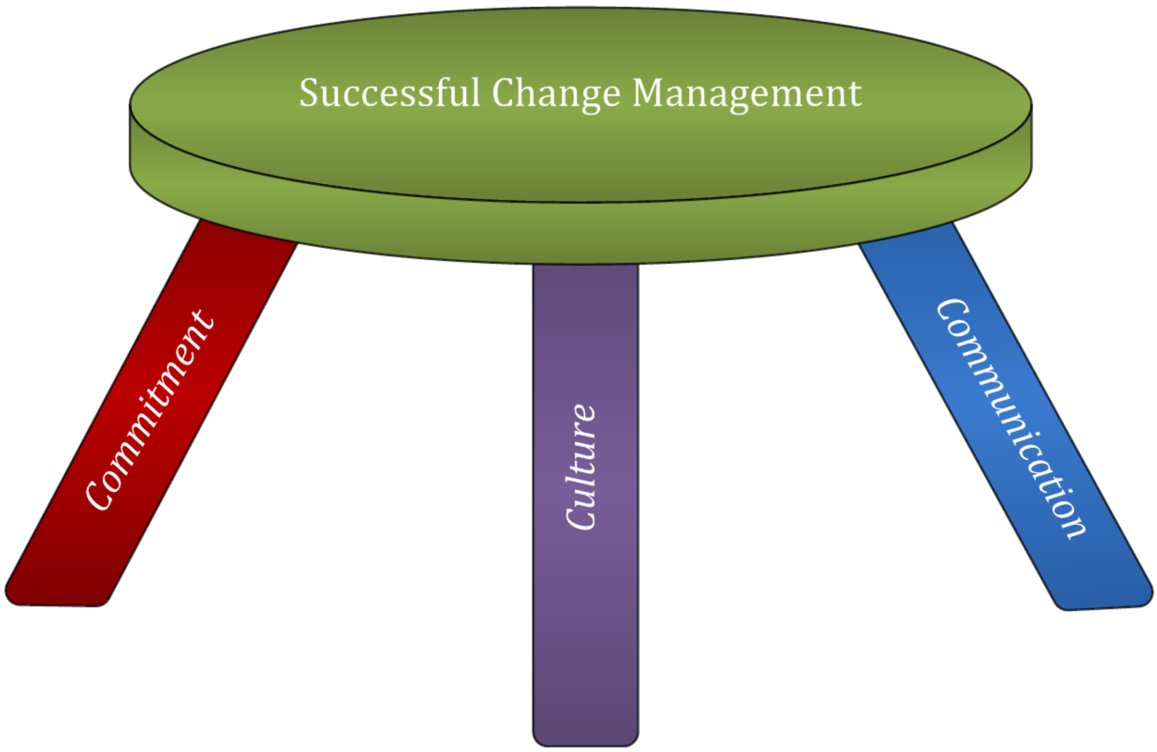


Figure 25: A simplified stool concept demonstrating the three pillars or aspects of successful change management. (T. Roosen illustration)

The model also creates a useful interface between higher level enterprises, such as lean change initiatives and creating a successful change result. This can be visualised by adding a further change element on top of the 'stool' representing the 'plane of successful change management' which can relate to any change enterprise. The application and validation of the model will be described further in Section 4.6 and used for the ultimate implementation of an environmental impact index which represents a change from previous practices.

4.4 Resistance to change, the role of culture and consequences

4.4.1 Understanding resistance to change and the role of organisational culture

Any change within an organisational setting will incur by resistance to the transformation, no matter how thorough the implementation, or how understanding and enthusiastic the participants might be. The idea of change itself is often the first reason for resistance from any of the organisation's personnel (Diefenbach 2007). People will inherently resist as a psychological reaction to a causal effect or outside influence, almost independently of the intent of the outside influence. Diefenbach indicates that many people can be quite 'sensitive' to the technical details of change including the how, where, when and why aspects as described previously. A key issue is the effectiveness of the communication, including discussion and consideration of employees. The effectiveness of communication is often correlated to the decrease or increase of resistance to change especially when employees 'feel' they have a voice in the upcoming change.

Changes are not always acceptable to individuals or groups. The force for change may be less than the collective group's resistance to it (Worcester 1970). Often even a small resistance to change can reduce the force for change by reducing the impact, isolating and not allowing the change to gain any traction within the organisation. However, when a major change has been effectively communicated and absorbed, over time the group will stabilise around the new norms. Even within an engineering organisation, where a logical flow of information and data is prized, change resistance is prevalent. While often an engineer creates change, this is not a guarantee that they will accept any external changes.

4.4.2 The role of organisational culture

Organisational culture can be described "... as a pattern of basic assumptions and beliefs, developed by a given social group throughout its history and includes internal and external adaptions which have worked reasonably well in the past to be considered the 'correct' way of interpreting organisational reality" (Schein 1990; Cabrera, F. et al. 2001). Thus a common 'belief' system is developed by a group as a response to external and internal influences and is used to carry out its functions. This system (developed by the collective) becomes a social norm and sets up overall structural boundaries within the organisation. The extent to which culture exists within a business or group is extremely varied from internal teams, departments or even within the corporation itself. The size of an organisation can also make a difference. A highly effective, efficient and organised small company may have a far more homogenised cultural appearance and belief system compared to a large, far-flung or cell-oriented corporation for which a greater variation in behaviour and culture extremes or beliefs would be present. While some of the larger, more prevalent cultural norms may have permeated through the entire organisation, underlying subsets or sub-cultural expectations and beliefs may be sequestered within different divisions or sections of the company.

As noted, the role of an overall corporate culture within an organisation is a fundamental component of reducing the inherent human psychological resistance to change. A wide variety of organisational cultures exist. Some are far more reluctant to change and thus minimise or reduce change impacts; while other organisations have instilled the concepts of continual improvement to their employees and encouraged a culture in which change is accepted and encouraged. This type of 'accepting' organisational culture environment is far more conducive to a successful reception and implementation of change initiatives (Chu 2003; Biloslavo and Trnavcevic 2009). Reinforcing this sentiment, Biloslavo states: “It is a well known fact that the introduction of changes more radical than required is unproductive for the company”.

The culture component of change management is a crucial tool for use in lean change implementation and specifically for the proposed change of a new environmental impact index. This is relevant in this thesis because of the perception held that lean practices produce a robust waste elimination culture (EPA 2000). Using a positive ‘continuous improvement’ culture already in place or creating a ‘change accepting’ culture allows the divisions and groups within a corporation or organisation to adapt, assimilate and become accustomed to the proposed changes quickly with less downtime. This helps smooth the transformation, when the collective ‘feels’ they are actively participating within a *known* event where they have some *control*. A *Change* of *culture* can be a solution to the resistance of the implementation of change concepts and company restructuring. Culture change or implementation could be the result of many factors, some of which include: internal factors, external forces, disorganisation, rapidly changing environment, reversing long standing ‘bad practices’ or ‘inefficient/unsafe traditions’ and seeking competitive advantages. The type of culture developed within an organisation is controlled by a variety of factors. Some of the controlling factors include: the business environment, values, heroes (leaders), rites and rituals and finally the cultural network or communication channels. Business environment is the factor viewed as the most influential on the establishment and evolution of culture within an organisation (Kurstedt Jr, Mallak et al. 1990).

4.4.3 The consequence of change and conditions favourable to change

Change management implementation can have both intended and unintended consequences that can lead to the success or failure of the implementation programme. The more important of the two is the unintended and undesirable change consequence. Biloslavo describes nine of the more common examples of unintended change consequence as illustrated in Figure 26 (Biloslavo and Trnavcevic 2009). The first consequence is decreased motivation of employees and resulting reduced productivity. This could be caused from an increasing complexity of tasks, mismatch of skill sets or miscommunication of change ideals. A second impact is decreased trust in management which further exaggerates the problem escalating an employee’s resistance to any change themes and ideas. The third consequence is the diminished innovation capacity of teams after losing both the trust of managers and reduced productivity. People feel less inclined to do ‘good’ work if they don’t perceive a positive end result or if they don’t believe in what they are doing. Negative impact of future initiatives, as the fourth consequence, is directly related to both the lack of innovation and motivation with the resulting failure in the positive feedback loop from management. A fifth consequence is a decreasing quality of services with greater resulting errors in work due to a worker’s lack of motivation and pride or ownership of products. As greater resentment builds due to enforced changes, the sixth impact includes further drastic action taken by individuals such as increased sick leave or other absences. The spiral may continue with redundancies. The tailspin of consequences compounds yielding reduced productivity and finally increased operational costs as the 7th and 8th impacts.

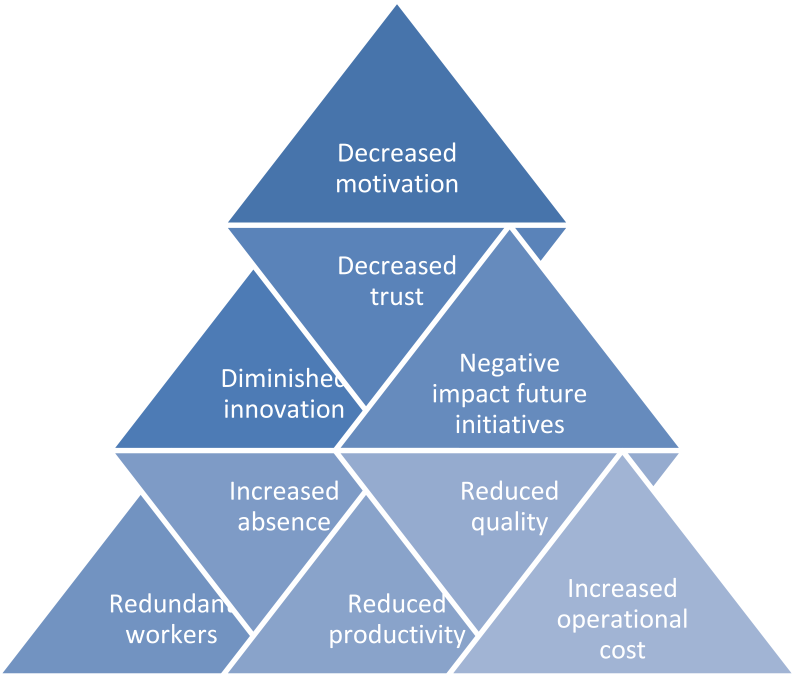


Figure 26: Change consequences (Biloslavo and Trnavcevic 2009)

Whilst this model is a relatively detailed description of change consequence, the Exit, Voice, Loyalty (tolerance), Neglect (blocking) (EVLN) model is a more simplified example of ways employees respond to dissatisfaction often produced by change. (Dyck and Starke 1999). The range of reactions to change are based around the behaviours exhibited by dissatisfied organisational members with a vertical scale of active to passive and horizontal scale of destructive to constructive. Exit and voice are classed as active-destructive and active-construction, whilst neglect and loyalty are classed as passive-destructive and passive-constructive respectively. These ranges of emotions can be compared to the nine change consequences previously described by Biloslavo. Both describe possible negative responses and the subsequence negative impact to the organisation as a result of change.

Several key suggestions have been developed in response to these consequences of change (Worcester 1970; Navarre and Schaan 1987). They are summarised as:

- Steer clear of large scale swift changes that don't allow acclimatization.
- Use inbuilt reward and communication systems within the company.
- Use possible altercations positively, so that people feel they are heard and that positive actions can result from arguments.

- Ensure that the programme / change initiatives do not rely on 100% achievement and they allow room for mistakes.
- Ensure respect is given to group opinions, beliefs and cultures, as well as cultivate an interest in making change.
- Use creative problem solving and adaptive training to yield a positive environment from which changes can be implemented.

4.4.4 Gaps in body of knowledge

After examination of a representative sample of change management literature, several gaps in the change management body of knowledge are apparent. The first limitation examined is the lack of integration throughout the separate change management models. The lack of integration stems from the inability for a single method or model to be used in every circumstance. It appears that each model is focused or tailored for a separate circumstance. This can result in a lack of a unifying theory that brings together and relates the separate models and paradigms proposed with a common underlying concept or framework. This leads to a second related issue which is the apparent lack in the predictive ability of the change management model. There is little guidance with respect to both the application of each specified method, as well as to what method should be used when and where.

The next gap in the current body of knowledge is the dominance of leadership-based models. The ‘leader’ of the change process is deemed the most crucial element or central figure in which the change transformation would fail without this lead role. Many change management models currently place significant emphasis on the need for a leader, without recognising the importance of the group involved in the change management process or the collective which implements the change. Greater focus should be directed to the critical pillars of commitment, culture and communication essential for successful change management as highlighted previously in Figure 25. This analysis also illuminates the need for a unifying and simplified set of change management operations that could be used in a *variety* of circumstances and scenarios. The focus on a single leader also exemplifies the commonly subjective opinions for both implementation and the results of the change process. Common practice dictates the results from the change transformation generally are in the form of subjective opinions on how well the leader or group thought the change improved the process with less objective data collection. The ‘experience’ of the leader is often relied upon to ensure a successful change process, as well as evaluate its usefulness.

Finally within the current models, there is a high prevalence of top-down change management concepts in which the change is pushed down throughout the organisation by top level management. Pushing change initiatives through the organisation have proven to be far less effective with a relatively low success rate, especially once the pressure forcing the change has been reduced or removed. People will inherently tend to go back to the state in which they were most comfortable. The less used alternative is bottom-up change implementation. This type of implementation is far more conducive to effective change management due to the very nature that those adopting the change process contribute very early on to the solution. Through communication of the required change, they become committed to the change and a ‘continuing improvement’ culture is developed at the base level in the organisation. The people adopting the change process and pushing the process up through the organisation are far more likely to continue the change culture if they are the ones initiating the process.

4.5 Change within the lean paradigm

This fifth section will focus on the interface between change management and lean manufacturing initiatives. (For a detailed review of lean manufacturing principles refer to Chapter 2.) The focus of this section is applying change management in a lean environment which is relevant to the proposed new VSM tool. To summarise, lean methodologies seek to reduce waste in its various forms using a predetermined set of tools that streamline production processes through a repetitive continuous improvement process. Lean manufacturing aims to reduce costs of production by eliminating Non-Value Added activities and is a common underlying principle in many major businesses and production facilities around the world (Abdulmalek and Rajgopal 2007). Lean processes are about preserving value within an organisation with less work and thus maximising efficiency. The benefits and detriments of lean production with respect to the change processes will be examined and discussed followed by a description of the barriers to success and a brief assessment of the cultural aspects of lean change. The final segment will outline the factors that create conditions favourable to change in a lean environment. This will assist the practical application of creating a new tool within the Pratt and Whitney environment.

The purpose of having a lean ideology through which change can be implemented in a system or organisational-wide approach stems from the often disorganised approach of trying to implement incremental change both in an organisation’s culture and a production system. The lean paradigm combines culture and effective change initiatives with useful streamlining production tools to provide a platform for which the foundations of system-wide transformation can be built. The key to this process is the cohesive approach for which lean tools can modify a business. It is acknowledged that a lean methodology is not the ‘perfect, golden solution, one step, simple fix’ procedure on which all organisations should be based. Rather this analysis shows the comprehensiveness and effectiveness that lean tools can provide when developing an organisation towards eliminating all areas of waste and especially when coupled with sound change management techniques.

4.5.1 Benefits of change management with respect to lean

The effects of change, through the implementation of lean production management, are varied and result in a range of benefits and detriments to an organisation. The primary benefits relating to change through lean processes are associated with the effectiveness of implementing the change, as well as system streamlining. The detriments are more closely associated with the improper use and implementation of lean change procedures. The change aspects of the lean approach examined will be both lean as a tool for change, as well as what changes lean processes might bring to a system. These aspects differ due to either the internal perspective of lean or the more system-wide perspective of change as a result of lean.

One of the prime benefits of lean change management is the elimination of Non-Value Adding activities, in other words waste. This change benefit is twofold through the efficient way in which overall system wastes (such as overproduction/processing, wait, motion, inventory and transportation) are reduced, as well as increasing product quality through reduction of defects and elimination of scrap and rework. This change type is related more with the effect that lean process management has on the operational procedures. On the other hand, one of the largest benefits of the lean implementation with respect to change management is the culture of change, as well as the associated continuous improvement ethic of lean principles. Lean production management relies upon building a culture where changes can be accepted so that improvements to the system can apply more often and accepted more easily, whilst involving everyone system-wide. The expectation of using lean tools is change. Creating a successful, efficient and continuously improving change culture is one of the largest change management benefits of a lean programme. The quality feedback and feedback control loop of the continuous improvement cycle and the constant questioning of system efficiencies is a another side effect as a result of using continuous improvement concepts tied-in with lean change management.

A common theme in change management is the push down from top level management of ideals, goals, strategic vision and change initiatives. Lean change management relies upon a less common but far more effective approach of pushing from the bottom up for change. Thus, workers and lower level management realise or start the change initiative and push it up through the organisation. This system is far more effective and more likely to be sustained, as the change is realised by those whom it will affect the most. The push aspect of lean is also complimentary to the way in which materials are scheduled, using systems such as Just-In-Time to reduce inventory and smooth production flow whilst not creating over production and storage wastes which assist change initiatives.

As a general change management system, lean production manufacturing management is an encompassing and efficient implementation tool. The lean methods can be applied to many circumstances, from using one or two tools to using the entire lean spectrum. Thus it is a very effective way to cross-apply concepts across the entire organisation within a common format. By applying lean tools to multiple dimensions of the company and removing waste, another benefit of this vehicle for change is the adjustment of focus from a purely dollar-orientated approach. Lean concepts also focus on quality and customer satisfaction, as well as waste reduction beyond just material waste. Finally, change through the use of lean concepts and tools helps decentralise leaders and responsibility and reduce the highly hierarchal structures that tend to exist in the modern organisation (Karlsson and Ahlstrom 1996). This decentralisation is a result of the cross-functionality and skills upgrade that is synonymous with lean implementation in which many members of the team take on different and expanding roles rotating leadership through the team to increase skill cross-over as well as efficiency.

Arguably the largest contribution lean methods have to offer is the inherent culture that results from lean utilisation. If a company has very few unifying cultural factors or perhaps even a fractured negative culture, lean methods provide a positive foundation and holistic organisation-wide culture that everyone from top level management to lowest level work can use in their day to day work. It unifies work processes and encourages adaptive continuous improvement through change (Karlsson and Ahlstrom 1996). A constant questioning attitude and creative solution-orientated approach is a powerful component of the lean culture which helps capture the combined creativity of an organisation to successfully realise company transformations.

4.5.2 Detriments of change management with respect to lean

Whilst many benefits exist with respect to lean change management, there are also several key detriments. The first most notable difficulty is the large change required and far reaching attitude that affects all tiers of the company demanding a significant change towards sustainability. The change requires standardisation of processes and materials, streamlining the work environment and allowing an effective continuous improvement cycle to develop. Another significant change focus relating to implementing lean manufacturing is the increase in quality. The term quality in this sense relates to the quality of tools, work done and materials. A high functioning adaptive organisation needs to rely on high quality stock to function effectively. Lower or poor quality will adversely affect the flow of production (Karlsson and Ahlstrom 1996). The concept of effective continuous improvement as a result of change in this sense is synonymously tied to the concept of quality; as one increases so does the other.

Another noteworthy detriment to the implementation of positive change initiatives is the improper use of lean as a holistic change management approach. The improper use of lean encompasses the lack of applying a complete set of lean tools. For example, improper use is only applying those tools which are deemed to be most effective or most relevant at the time. Another important aspect corresponding with lean tool misuse is the possible side effects of lean processes. For example, an increase in productivity and efficiency means fewer workers are required to do the same tasks for the equivalent amount of work. Those unaccustomed to a total lean approach would remove the ‘waste’ resulting in a negative change, instead of applying other lean change principles which advise the redeployment of this new found or ‘freed up’ resource. This poor implementation of lean leads to greater risks to individuals within the organisation, consequently creating a strong resistance culture towards lean initiatives.

Ultimately, it is the poor implementation of lean principles that lead to misguided and non-constructive changes instead of a proper use of the lean tools themselves. Lack of understanding with respect to both a local and most importantly a global use of lean tools is a key determent to change. Lean thinking and lean thinkers can also be viewed as a disturbance to systems due to the continuous improvement attitude and the constant questioning that comes with a lean change enterprise. Angst can sometimes arise between ‘lean’ and ‘non-lean’ thinkers as a result of a lean focus on intrinsic imagination and creativeness, as well as the encouragement of implementing new unfamiliar ideas. Occasionally there can be classification of those who use lean methods as presenting a threat, which is a significant detriment to an organisation’s change implementation and even internal culture.

Implementing a new environmental index within the VSM environment of the Christchurch Engine Centre (CEC) will require that all these detriments to be taken into account.

4.5.3 Summary of barriers to success when implementing lean changes

Several key factors can create situations in which lean change initiatives are less likely to succeed. These barriers to success are essential in defining so that the implementation of the purposed new environmental index methodology has a higher chance of success. The key elements are briefly summarised in the following bullet points.

- The first barrier to success is the fracture or nonexistent culture that might exist before the implementation of lean change. There is also the danger of a negative paradigm in which tradition dictates change; people do things as ‘like they always have been done’.
- Another barrier is an unaccepted cultural and managerial consequence due to decentralisation of leadership. A highly hierarchal organisational structure can be counterproductive as top level management might feel threatened with respect to job security.
- The personal self preservation of individuals might create further barriers to success as individuals might consider the change not in their ‘best interest’.
- Lean can result in a high stress environment that can often lead to conflicts in views and perception due to the always questioning and always striving for perfection environment.

- Time frame limitations may reduce the effectiveness of the lean change implementation, thereby creating a negative time-wasting paradigm. Time management is crucial and must be monitored to ensure set goals are reached.
- The use of lean as a reactive tool to 'put out fires' instead of a proactive tool to change the future state of the business can lead to a negative view of lean's effectiveness. Lean should not be used in desperation or as a last ditch effort to save business, but rather as a conscientious decision to adopt a new way of doing business.
- The lean paradigm is often hard to visualise and hard for people to establish what the personal gain might be. The big picture can often be overlooked at the cost of personal gain.
- Another difficult concept to overcome is that good is never good enough. People will often become demoralised due to the continuous improvement environment in which 100% is never reached but always set out as a target

4.6 Conditions favourable to change with respect to implementation of lean

As with the barriers to success, there are several key conditions that can be generated that increase the likelihood of successful lean change implementation. These key factors will be applied when implementing the proposed environmental VSM methodology at the CEC. The conditions favourable to effective lean change management are summarised in the following bullet points with the focus being the use and application of the proposed change of a new environmental index.

- ***Use developed model of the Three C's (i.e. communicate, culture, and commit) to help adapt current system and implement a successful change transformation.***
- Adopt overall process of lean change and not just one or two specific one-off events or tools that might appeal at the time.
- Appeal to the inherent culture of lean, specifically how change is treated. The culture of lean is one of change and encouragement of change, as this impacts improvement.
- Cross-train staff so that a multi-faceted working force is created allowing for easy adaption and redeployment of staff with respect to new situations and varying customer demands. A far more adaptive and responsive system is more conducive to successful change initiatives.
- Focus on the perpetual evolution of lean principles and creating a paradigm of continuous improvement.
- Lead by example. Top level management **must** participate in the change and ensure participation from the lowest level worker. People inherently learn from example, and if a learning environment is created by top level management, success if far more likely.
- Create progressive positive challenges to encourage people to grow. Create achievable goals that also push the organisation to achieve using lean as an enterprise system. This establishes lean as a tool for success by providing positive reinforcement.

- Reward initiatives even if they fail. This encourages problem solving and use of the imagination of employees and creates a far more adaptive environment conducive to change.

4.6.1 Validation questionnaire

To validate the effectiveness of the change management model (as applied to the CEC during the implementation of the created environmental value stream mapping methodology), a series of seven questions will be solicited from the participants testing the new environmental index. Three of these questions will relate to testing the effectiveness of the change management relative to the new index. Successful communication of how to implement the lean environmental impact index and the overall appreciation for understanding environmental waste will correspond to an increase in practitioner understanding of environmental waste and the increase in awareness of environmental aspects. The questions are:

- The first question focuses on importance of waste measurement and will be: “To what extent do you think it is important to measure environment waste impacts?” (Question 1)
- The second aspect of culture can be expressed as the openness of the practitioner to continuous improvement; a concept synonymous with both lean manufacturing and CEC’s organisational vision. The culture aspect will be verified by asking: “To what extent do you think the tool was successful in prompting new thinking and continuous improvement?” (Question 3)
- The final characteristic of commitment can be described as the self-efficacy of staff to implement the index; as well as the continued motivation of staff in using and improving the index. This factor is examined by asking: “What did you find difficult? (Or if you could change one thing what would it be?)” (Question 7)

The questionnaire approved by University of Canterbury ethics committee can be found in Appendix D. Figure 27 shows the developed change management model with its associated descriptions and the related three questions used to validate its effectiveness.

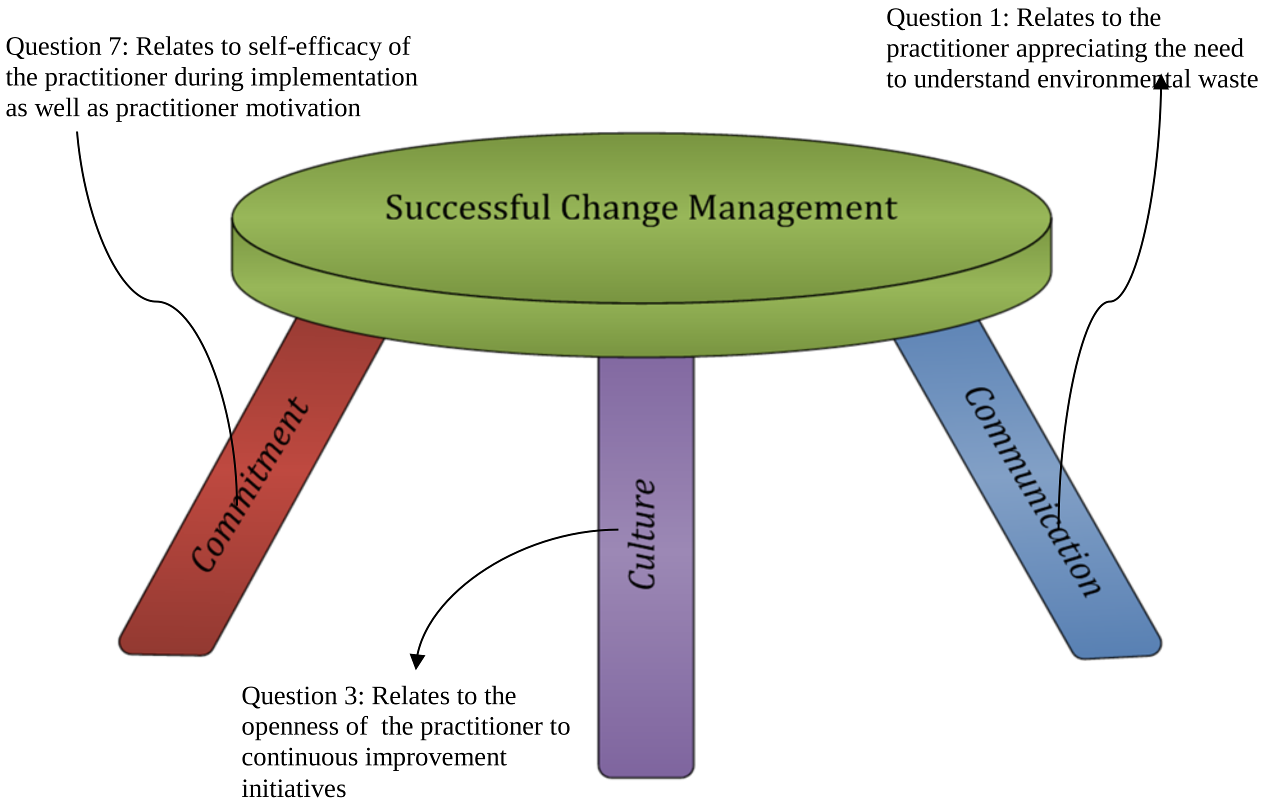


Figure 27: Validation of change management model using questions 1, 3 and 7 of questionnaire (T. Roosen illustration)

4.7 Summary

This chapter examined various general engineering change management methods in an effort to create a simplified effective model for educating practitioners in the implementation of new practices. An examination into overall models of change management, as well as specific change management methods resulted in the distillation of three facets of change believed to be the most important elements conducive to successful change management. The facets are: communicate, culture and commitment. Once the model was developed, resistance to change, the consequence of change and conditions favourable to change were explored to ensure a successful implementation of the new lean manufacturing tool. The focus of the second section re-examined change paying greater attention to the concept of lean change transformations. The benefits and detriments of lean change were explored, along with a further analysis of barriers to successful lean change and conditions favourable to lean change initiatives. The focal point of this chapter was the development of the three facets (communication, commitment and culture) change management model to provide an interface between higher level enterprises, such as lean change and the success of change management initiatives. All three aspects—commitment, communication and culture—were used in the implementation of the environmental index incorporated into VSM and the model aspects were validated through the use of a post implementation questionnaire.

5 Methodology

5.1 Current gaps

The concepts of traditional waste management have continued to progress over the last 20-30 years as the importance of eco-friendly concepts begin to take a greater forefront in production and engineering. This has been enhanced by greater levies on waste by governmental bodies leading to greater waste management implementation by manufacturing and construction organisations. Lean production with respect to lean principles and the eight wastes has also progressed since its inception in the 1950's. Both of these two 'waste' fields have been highlighted in the previous sections of environmental / waste management systems and indices, as well as the literature review covering lean implementation tools and management.

A strong conclusion from this study reveals what is lacking is the integration and assimilation of the traditional waste management approaches with that of the lean manufacturing approach to waste. This is particularly apparent with respect to environmental mapping, as there has been relatively little exploration of Environmental Value Stream Mapping (EVSM). Only a few examples have been identified. (e.g. The EPA has been able to extended VSM principles to take into account traditional waste by creating EVSM's with respect to hazardous waste for example.) This represents a significant gap and opportunity for improvement, particularly in manufacturing and production industries.

Thus, this thesis has focused on the need to further explore the relationship and expand the body of knowledge to better interrelate environmental waste measurement and lean production engineering in the field of VSM. The second part of this paper will explore a practical application of these concepts focusing on VSM's at the Pratt and Whitney, Christchurch Engine Centre (CEC). The goal is improving and broadening the use of VSM, as well as investigating a way in which environmental impact assessment could be integrated with VSM use at the CEC.

5.2 Key focus: a need to integrate environmental factors with lean

Traditional concepts of environmental waste focus on the total production of waste from a plant. Production engineers are therefore interested in quantifying the amount of waste and its consequences on the natural environment. Hence, there is an emphasis on containing waste within the plant boundaries and applying post-production processes to eliminate or minimise the impact following the waste hierarchy, as illustrated in Figure 15.

There is a growing awareness of the importance of incorporating environmental factors into lean processes. As previously discussed, there have been a number of initiatives in this direction. Integrated Definition for Functional modelling (IDEF0) is one method to incorporate an existing waste index (Patil 2002). The United States Environmental Protection Agency (EPA) has developed an Environmental Value Stream Map (EVSM) which focuses on one particular form of waste but lacks the ability to focus on environmental waste as a whole or even multiple environmental wastes.

However, the future will also require reduction of waste at its point of generation. Waste is generally not generated by a plant in total, but by individual processes within the production stream. Therefore, focussed management of environmental waste requires that production engineers first know what the waste is and where it is being generated. This is the crux of the problem, as this is often simply not known with any accuracy. In addition, production plants are controlled and improved by lean methods. If some waste is not visible to lean methods, then it will not be included in the continuous improvement cycle. It is therefore imperative to embed the environmental issues into lean tools.

This exploration has shown there have only been minor developments in creating an overall value stream environmental impact index and an encompassing methodology. The objective then is to develop a way to include environmental waste alongside other lean production wastes. If this is achieved, then the organisational momentum and culture that sustains the lean initiatives will automatically ensure that environmental waste is included in the decision making process.

5.3 Approach taken

The approach taken to create a comprehensive environmental impact analysis methodology was to initially set up research collaboration with a local industry partner. (See industrial context, next chapter.) The Christchurch Engine Centre (CEC) which provides remanufacturing services (as a precision engineering plant) was selected. The firm already had an established process for implementing VSM, but did not incorporate an environmental impact for each process. This was important step for the firm for two reasons:

- Some processes can involve toxic materials
- The reduction of environmental waste was seen as a strategic competitive advantage.

Resolution of this problem was approached in the following way. First, a composite environmental waste index was created. Then a variety of environmental impact factors were integrated to form a single new impact index that was relevant to the operational purpose of the firm. Given that adoption within an organisational culture was important for the success of any new initiative, several different concepts on how an index might be visually represented were created within the VSM framework. Focus groups were also used to validate the index factors and the visual representation from an industrial perspective.

From this, the details of an integrated environmental waste-VSM method was designed. The design was shaped around the existing VSM which is the dominant lean tool used in this type of industry. The development included a method to represent multiple dimensions of environmental waste (in this case five) for each process in the value stream. Further, the development included a way to represent the aggregated environmental waste for the whole value stream. This permited the methodology to scale with the production hierarchy. The beta test methodology was deployed within the context of a Pratt and Whitney-VSM. The test was accomplished on actual production lines and monitored user responses.

6 Industrial Context: Christchurch Engine Centre Overview

This chapter focuses briefly on current Value Stream Mapping (VSM) use at the Pratt and Whitney Christchurch Engine Centre (CEC) along with suggest improvement initiatives for VSM applications.

6.1 Current use of VSM at Christchurch Engine Centre

As part of the Achieving Competitive Excellent (ACE) operating system, VSM is a known and widely practised lean manufacture tool within the CEC. Value Stream Maps are primarily used by higher management to monitor and improve remanufacture and information flow. Table 4 shows a sample list of the current and future state VSMs conducted on site at the CEC.

Table 4: Sample of VSMs conducted onsite at the CEC (current and future state)

Process	**Current state map**	**Future state map**
Shop visit reporting	Yes (electronic copies)	Yes (electronic copies)
Work Scoping	Paper copy 2008 (requires electronic conversion)	Paper copy 2008 (requires electronic conversion)
Repair Insertion	Paper copy 2008 (requires electronic conversion)	Paper copy 2008 (requires electronic conversion)
Technical Publications, OEM review processes	Paper copy 2008 (requires electronic conversion)	Paper copy 2008 (requires electronic conversion)
Correspondence Logs	Yes (electronic copies)	Yes (electronic copies)
Solumina Business Operating System	Yes (electronic copies)	Yes (electronic copies)
Certification Process	TBC	TBC
Remanufacture lines (V2500, Dart, JT8D)	Yes (electronic copies)	Yes (electronic copies)

6.2 Real time case study

To understand the entire repair process within the CEC, a real time case study was conducted. The intent of the case study is to view the method that the CEC uses in conducting a VSM. The specific process examined was the Piece Part Process (PPP) from receipt to despatch and final invoicing. Using the PPP, individual engine components are sent to the CEC for remanufacture and repair. This differs from the normal process of receiving an entire engine for repair and maintenance operations. The nature of both the small scale of work and the small batch size results in the PPP's return on investment just breaking even and often operating at a loss. This has brought about a drive by management to try and reconfigure and optimise the PPP so that the same quality of service can be provided with a more positive cash flow and turnaround time.

The examination of the VSM for the PPP is separated into three stages of analysis. The first details the underlining problems specifically associated with the PPP. The second stage is a review of the positive steps taken throughout the VSM. The third stage is a series of suggestions that could be used to help improve the VSM implementation at the CEC. These three aspects of the case study will be examined with the intent of applying the lessons learned to the implementation of a new index.

6.2.1 Underpinning problems with PPP

The primary concern when preparing to do a VSM for a process such as the PPP is the complex, splintered multi-level nature of the process. The PPP is a process which consists of many minor, low dollar value work parts with very large work scope variations. The difficulty in this type of system is that generally there are no criteria or prepared standard work documents / procedures for each part being assessed. A contributing factor to this conundrum is associated with over-scoping 'Piece Parts' as they are processed throughout the remanufacture facility. The high quality of workmanship at the CEC leads to over-inspection, often beyond that which is required or asked for in the original customer requirements. Employees tend to inspect each part in great detail to ensure that the CECs high quality is assured, but often finding faults or flaws not within scope.

A typical example is if a part comes in for general inspection and painting, often the inspection and repair costs that are accomplished will outweigh what the customer can be charged. Another example is that if an inspection does find inherent flaws or defects and the customer decides to buy a new part instead of a repair, the cost of inspection and / or repair on the original part is not recoverable. A very careful balance is therefore required between assessing the part for repair to the level of detail asked by the customer and the quality of remanufacture that CEC wants to provide; as well as the realistic cost of repair or replacement. The CEC is not required by law to repair or inspect the rest of the part outside the initial customer notification. However P&W wishes to remain a quality and responsible name providing a high standard of work and a thorough job. One possible solution considered is a 'competitive price' or 'real' cost estimation, which comes at the risk of losing customers for too highly priced components.

6.2.2 Review of positive steps taken during VSM implementation

The second stage of the critical review is a discussion of the positive steps carried out during the VSM implementation for the PPP. The first notable point is the detailed set of notes available on the CEC database for VSM symbols, implementation and use. As part of the requirements for the ACE certification, the CEC applies VSMs throughout many facets of its organisation to help improve its operational management. The CEC has also started to convert many of the paper VSMs into an electronic format to help increase accessibility to the documents. This also increases the ability of VSM charts to be changed or modified when required.

On the first day of PPP-VSM implementation, a participant had already taken the initiative and provided a brief current state VSM map for most of the PPP to help speed up initiation of the VSM event. This allowed participants to complete the current state VSM within the first day. Constructive conversations and criticisms during the event were another element that lent a very positive note to a productive outcome throughout the implementation. Employees were encouraged to discuss, suggest improvements, dissect ideas and propose solutions. Discussions on standard work (another lean manufacture principle), as well as ACE elements helped identify ways in which the standard operating procedures could be applied to improve the PPP. Development of the current state VSM included Kaizen events for improvement which were also very productive, leading to additional key areas in which improvement to the PPP could be applied.

6.2.3 Suggestions to improve VSM implementation

This case study brought up several areas that could be targeted for improvement. These are of particular importance for the development of a new index since this same process will be used. The first noticeable change between an actual VSM implementation of the PPP and a theoretical concept was the variation of participation on each day of the event; as well as the focus of discussion throughout the day. The participation consistency factor is relatively minor. As with any busy organisation, general participation will vary from each session due to other meetings, work deadlines and general availability. This is unavoidable. The focus of each session, however, could be improved if at the start of each day or each sitting, the topic for discussion was clearly outlined and noted. A review of past session(s) could also aid outcomes. Several digressions were noted from current VSM discussion to future state VSM and possible system changes, which occurred all within the first session. It would be beneficial as a time-saving and problem-focusing activity if participants were aware of what the focus was for a particular day and kept ‘on topic’. Clearly highlighting future states and problems during a current state mapping are beneficial, but these could be noted by the group leader and discussed at the appropriate session.

Another area for improvement was the digression of focus when discussing possible changes to the system dynamics, as well as a concentration on perceived ‘problems’ in the system instead of deciding on Non-Value Added (NVA) and Value Added (VA) activities. The classification of activities in terms of VA and NVA allows a VSM process to be mapped with ease and time-wasted processes to be identified swiftly. On the other hand, if participants try and improve the system just by resolving or changing ‘problems’, the root cause of system time-wasting activities might not actually be found. Thus, throughout VSM implementation defining VA and NVA concepts helps participants keep in mind the separation between these different types of activities, thereby allowing greater accuracy in determining a system’s flaws and weaknesses.

One of the most important notable departures from a fundamental application of the VSM methodology is the knowledge and use of standardised VSM tools and symbols. The ability to communicate through a common medium is of vital importance. During the PPP, there was considerable confusion with respect to what each symbol represented; how the entire VSM should be displayed; what each type of line meant; and what should be described in the data acquisition box; as well as the separation of NVA and VA time for each process. An important aspect of the VSM process is ability of past and future maps to communicate ideas, as well as providing clear communication with each participant throughout the implementation. VSMs have a common set of mapping symbols and data acquisition boxes and these should be displayed on a chart throughout the mapping process so that all VSMs created are identifiable and universal.

Increased participation at an early stage of all interested parties concerning the focus of the VSM event might also be conducive to gaining a faster VSM process. Having at least one representative of all interested parties present would possibly lead to greater intercompany communication about flaws in the process, as well as allow each department to have their say in improving and implementing change. This again depends on time-tabling and scheduling between various parties.

Lastly, the method in which both the information and part flow VSMs were drawn varied from standard practice. Typical VSM conventions indicate that single VSM should contain a single horizontal work stream or process with respect to information or material flow through a system. In this instance, the current state VSM for the PPP contained a primary information flow and a secondary part / material flow map underneath. The secondary map was drawn as a reference but VSM best practice recommends that a separate map should be drawn per value stream type. This real time case study provided a working model in order to verify effective methods that could be used in creating the new environmental index.

6.3 Summary

Prior to moving into the implementation phase of the new environmental index, a summary review is provided. Previous chapters have provided a literature review on the properties and constituent components of the VSM process, as well as the origin of the VSM tool within the lean manufacturing system. The literature review included information on the critical stages of the VSM process, as well as strengths, limitations and gaps in the body of knowledge of literature regarding VSM compilation. A real time case study was critically reviewed in three stages. The first stage discussed the underpinning problems of a Piece Part Process and a current VSM focus. The second stage discussed positive steps conducted throughout the VSM implementation process. The in-depth review was also able to provide a sound base in which a critical review could be launched and successfully explored for possible changes to the current VSM implementation practices at the CEC. The next step is development of a new environmental waste impact index and incorporation of it into the VSM process at CEC.

7 Results: environmental waste impact index creation and incorporation

7.1 Developing a new index

This chapter describes the development of the Environmental Impact Index (EII) and incorporating a framework, along with visual representation of the results. The chapter examines possible visual displays that will represent the chosen index, as well as what can be easily integrated into current VSM maps. To consolidate the disparity gap between overall site waste data and process level information, two main design criteria were required to be met. The first criterion required to consolidate the disparity was to create or modify an appropriate waste index and encompass this index into an overall evaluation methodology that could be used to determine specific environmental impacts at the process level. The second criterion was to create a robust visual representation method that would effectively highlight high environmental impact processes that required Kaizen (in this case waste reduction) initiatives. Thus, the development of this index and its visible representation are the themes of this chapter.

7.2 Integration of environmental factors with lean

As highlighted in past chapters, current concepts of environmental waste focus on the total production of physical waste from a plant. Most waste programmes are interested in quantifying the amount of waste and its consequences on the natural environment. Hence, there is an emphasis on containing waste within the plant boundaries, applying a post-production process to clean it up according to the waste hierarchy (Figure 15). However, total waste management as defined by lean principles will also require reduction of waste at its point of generation. Waste is not generated strictly by a plant but also by individual processes within the production. Therefore, focussed management of environmental waste requires that production engineers first know where the waste is being generated but this is often not known. In addition, production plants are controlled and improved by lean methods, and if some waste is not included with the lean methodology, then it will not be included in the continuous improvement cycles. This thesis has concluded so far that it is therefore necessary to embed the environmental issues into the lean tools for a total waste management.

To consolidate the disparity gap between the overall site waste data and process level information two main design criteria were required to be met. The first element to consolidate the disparity was to create or modify an appropriate waste index and encompass this index into an overall evaluation methodology that could be used to determine specific environmental impacts at the process level. The second criterion was to create a robust visual representation method that would effectively highlight high environmental impact processes that required Kaizen (waste reduction) initiates.

7.3 Waste index - design considerations

After various meetings and consultations with the CEC relative to a suitable index, a number of design considerations were crafted. A summary of these design considerations for the index are shown in Table 5.

Table 5: Summary of waste index design considerations

Waste index design considerations
Simplicity of method
Simplicity of calculation
Ability to incorporate volume of waste (or equivalent)
Ability to incorporate toxicity (or equivalent)
Ease of integration with visual representation
Adaptability of index to measure/highlight different environmental impacts (waste types)

7.4 Visual representation of index - design considerations

A review of the VSM process in relation to a new index also occurred at the CEC. A sample VSM was reviewed contrasted with the purposed supplementary waste map and current VSM. This is shown in Figure 28. A Kaizen event can thus be created once key high impact processes displayed by the created impact index and subsequent visual representation have been identified.

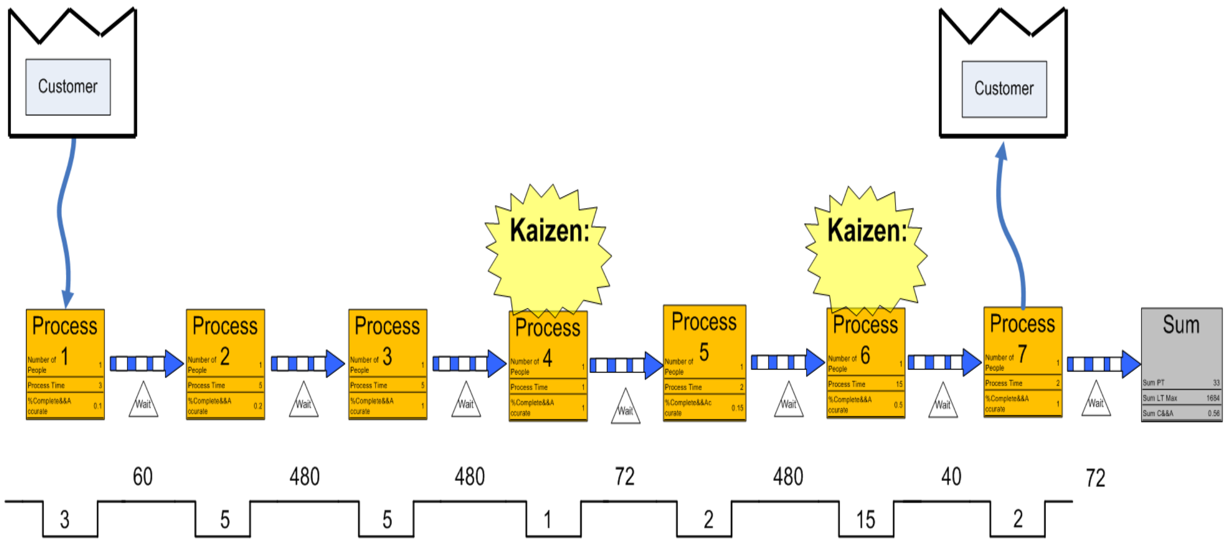


Figure 28: Simplified generic single stream VSM used as visual aid and comparison

This review revealed that the visual display of the new index needed to integrate with a standard VSM. From this discussion, various other design considerations for the visual representation of the index were developed. These visual representation - design considerations are indicated in Table 6.

Table 6 - Visual representation - design considerations

Visual representation – design considerations
Ability to integrate with the standard VSM
Clear and effective communication process that require Kaizen events (for waste reduction)
Clear and effective display of data
Ability to display multiple dimensions of value
Time required to create
Ease of use

7.5 Reviewing nine indices to the design considerations

A series of nine possible environmental waste impact indices were examined in Section 3.3 and these are summarised in Table 7 **Error! Reference source not found.**.

The original nine waste indices were described in Section 3.3

Table 7: Summary of indices examined

Nine waste indices	*Reference Section*
ISO 14000 Indices	**3.3.1**
EPA – Lean and Environment Toolkit	**3.3.2**
Environmental Management Accounting	**3.3.3**
Total Emissions Method	**3.3.4**
Systematic Environmental Assessment	**3.3.5**
Volvo- Environmental Priority Strategies	**3.3.6**
Carbon footprinting (Greenhouse Gas equivalent)	**3.3.7**
Global Reporting Index	**3.3.8**
Lean Waste Measurement & Custom Index	**3.3.9**

7.6 Evaluation of nine indices with waste index design considerations

An evaluation took place of each of these nine indices with weighted index design considerationsshown Table 8.

Table 8: Initial index evaluation table using primary design considerations

Index system										
Category	**Weight**	*3.3.1 ISO 14000*	*3.3.2 EPA tool*	*3.3.3 EMA*	*3.3.4 Emissions*	*3.3.5 SEA*	*3.3.6 Volvo system (*Adapted)*	*3.3.7 Carbon*	*3.3.8 GRI*	*3.3.9 Custom Or risk*
Simplicity of method (1 complex - 5 easy)	***5***	1	1	1	4	2	4	4	2.5	5
Simplicity of calculation (0 if none)	***5***	0	0	0		0	3.5	5	2.5	4
Ability to incorporate volume of waste (or	***5***	5	0	5	5	0	5	5	5	5

equivalent)										
Ability to incorporate toxicity (or equivalent HSE value)	***5***	3	0	1	5	2.5	5	5	5	5
Ease of integration with visual representation	***5***	2.5	0	2.5	2.5	0	5	5	5	5
Adaptability of index to measure/highlight different environmental impacts (waste types) through the use of a filter or scaling factor	***10***	7	0	2	0	10	10	10	10	10
SUM	***35***	18.5	1	11.5	16.5	14.5	32.5	34	30	34
Percent of maximum score	-	53%	3%	33%	47%	41%	93%	97%	86%	97%

This revealed that five of the indices were more suited for the purpose of this research. The indices that were deemed unfit for purpose fell below a chosen benchmark of 80%. These were:

- the EPA toolkit
- EMA method
- Emissions index
- SEA index

The EPA toolkit, EMA method and ISO 14000 were omitted due to their low score in the ease of use, ease of integration and adaptability categories. The Emissions and SEA index were omitted as they were deemed too specific and could not be adapted to different forms of waste or environmental impact scenarios. ISO14000 was originally omitted at this stage of the project due to several limitations. However, it was noted that it was the highest scoring index in the omitted selection. Thus, it was determined to include ISO 14000 as a secondary alternative and to ensure unbiased selection of an appropriate index.

Thus, the indexes to be considered further were:

- an adapted Volvo environmental priority system
- a simple carbon footprint index
- the use of GRI index

- a simplified risk and consequence index
- and the reinstituted ISO 14000.

The following is a brief description of the benefits and detriments of each of the five possible indices.

The primary benefit of the Volvo priority system is the ability for the system to take into account key environmental impact factors, such as cost to reduce emissions, permanency of effect and extent of affected area. The detriments of the Volvo priority system (relative to the design criteria)were that the system would need to be adapted to include a direct measure of environmental impact and it lacked an ability to include both volume of waste along with some form of toxicity measure. While these are significant changes, one option is to use some of the positive concepts proposed in the Volvo priority system but included in an index designed specifically to reflect the requirements of the CEC.

The second proposed index is the simplified carbon equivalent system. The primary benefit of using a carbon equivalence index is that the result of the analysis would be in units used and recognised widely around the world. The concept of carbon credits and carbon reduction programmes have become increasingly important due to the impact that Greenhouse Gases (GHG) have on global climate change. Another advantage of using the carbon based unit of measure is that employees, customers and external users would be able to directly relate the measured output of the index with the environmental impact of the process. A third benefit would be the potential customer gain and worldwide recognition that the CEC would demonstrate in its initiative in tackling the carbon footprint problem by using carbon footprint as a direct measure of its environmental waste. This could potentially result in a significant competitive advantage for the CEC and create a positive 'environmentally friendly' image. One of the primary detriments for the use of the carbon equivalence index is that there might not be many direct measures or known conversion factors for a significant portion of the CEC waste types.

The principal benefit of the GRI system is its world recognised use and subsequent standard operating procedures. Using the GRI index would allow a direct comparison of the environmental performance between the CEC and companies worldwide. This might also represent a severe detriment in the inability for the GRI to highlight or focus on specific wastes types. Another detriment of the GRI system is the broad and complex nature in which calculations are conducted for each element. This complexity is not conducive to incorporation into current VSM events. The proposed process needs to be as simple as possible so that various skill levels can use and understand the index. Another disadvantage of the GRI is the complexity of final results that are the output of the elements for this evaluation. It should be noted that this complexity would also not be conducive to the creation of an effective visual representation which is to show the environmental impacts of the varying processes.

A risk and consequence scale would be beneficial due to the established methods where risk and consequence matrices are created. The severe limitation of risk and consequence matrices is the lack of ability to take into account and display various forms of waste impact. The final impact would just be a summation of subjective risks that could vary from process to process and system to system.

On the other hand, as the last option, the ISO14000 standard covers a wide variety of environmental impacts in great detail. This is also one of the main failings of the ISO14000 standard in this particular case. The ability for the applied index to be used by any practitioner skill level, as well as be applied to the system in a swift manner would mean the ISO14000 standards are not particular suited to the purpose of this application.

An additional option added after the evaluation of the above established indices is creating a custom scale or index. This has several advantages and limitations. The first limitation of a custom scale is the lack of verified results or supporting evidence to prove that the created index can provide a clear relationship between the process in question and the end environmental impact. Whilst initially this might seem a severe detriment, upon further consideration a custom index provides several advantages. The first advantage would be the ability for the index to provide a multi-level layered measurement. Thus, the weighting scale for a specific waste could be changed as required to reflect company goals, as well as highlight specific environmental consequences. An example would be to rate recyclable material as a very low ranking in the index and emissions, or extremely hazardous material as very high. This flexibility allows the index and visual representation to highlight those processes that have 'high' environmental impact. This adaptive, evolutionary quality would allow users to pre-determine 'goal reduction wastes' or target wastes and use the index and VSM process to highlight problem processes. Another important aspect of the custom scale is the ability to add or remove indices for a specifed application. A further advantage is the inclusion of a volume weighting that would allow process to be highlighted that might not have high toxicity but do have a very high volume.

7.7 Reviewing visual representations

In addition to a review of indices, a series of four visual options were developed for review. These options are briefly described in the following section which contrasts the options to the design considerations for visual representations .

7.7.1 Bar graph concept

The first purposed visual concept was a simplistic bar graph that would reside beneath the VSM. The X axis would represent each process step or stage, whilst the Y axis would signify the amount of 'waste' for each process, as shown in Figure 29. This system would also integrate three trigger colours red, orange and green to further illustrate poor, neutral and good processes respectively. The colour of each bar would change once a predetermined percent or threshold had been reached with respect to the chosen index or scale on the Y axis, progressing from green to orange to red. This colour difference would further highlight and help swift identification of processes which require Kaizen initiatives. The use of either a positive or a positive and negative scale could be appropriately adapted. If both a positive and negative axis were used, the index could be designed so that processes that reside on the positive side of the scale would be ignored and deemed low waste or error. Whilst those on the negative side would be deemed large waste or environmental impact processes. A simplification to the graphing process could be used so there is just one positive scale. This would ensure that no confusion is made between negative and positive processes, as well as their associated colours and whether a Kaizen is required or not.

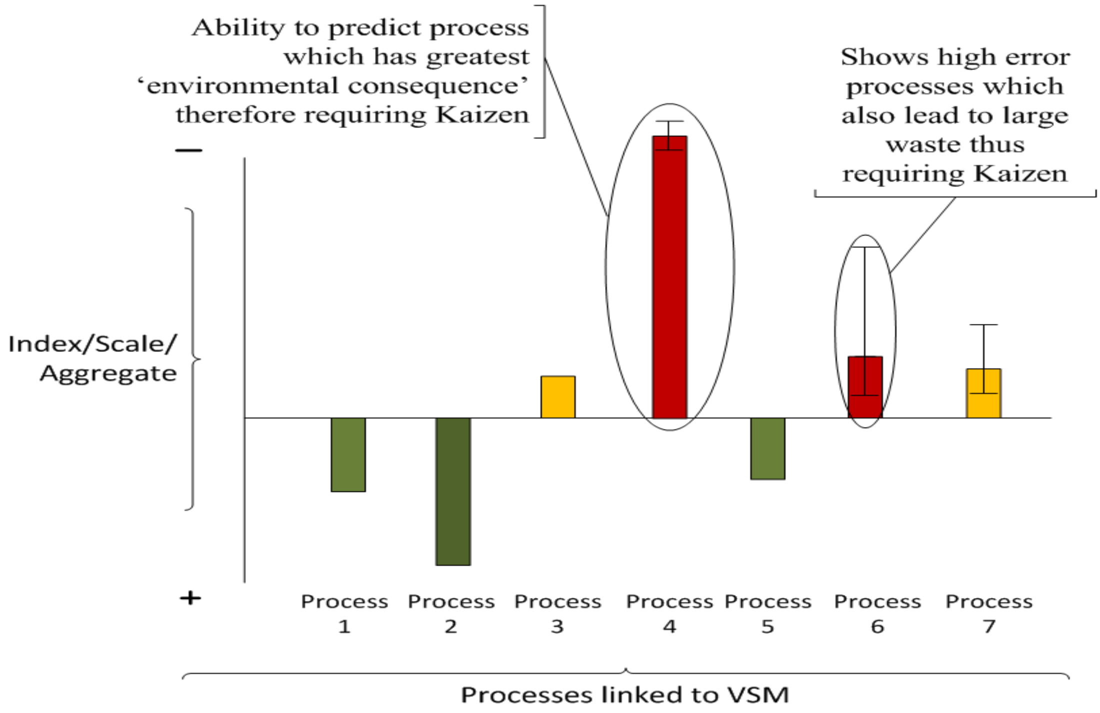


Figure 29: Option 1 - Bar graph representation of environmental waste or impact that would be displayed underneath existing VSMs. This shows both a positive and negative impact. (T. Roosen illustration)

In addition to the bar graph, an error bar overlay could be used to determine processes which have low accuracy in terms of measurement of the waste amount or waste impact. High error in the respective process is commonly deemed as a very large contributor to overall waste. Thus, with the secondary visual aid of error bars, the processes that have a low ranked index amount but high error would be easily identified for Kaizen events against those processes with a slightly higher index ranking but exhibiting lower error.

7.7.2 Process chart concept

The second purposed visual representation is a simplified process flow chart that would reside directly below the drawn VSM, as shown in Figure 30. This concept takes the colour aspect of the bar graph option previously discussed and simplifies it, so that just one coloured box is shown per process. The colour would directly reflect the pre-determined environmental index, so that high impact processes would be displayed as red, neutral as orange and low impact processes as green. Those processes that have a red box would be easily identified as those requiring immediate Kaizen implementation. Greater precision of impact results could be achieved by including a greater number of colours and relating consequence. This visual representation would not directly show the volume, impact or error associated with each process, but it could use an algorithm to calculate the index and compare that to the pre-determined thresholds for each consequence scale.

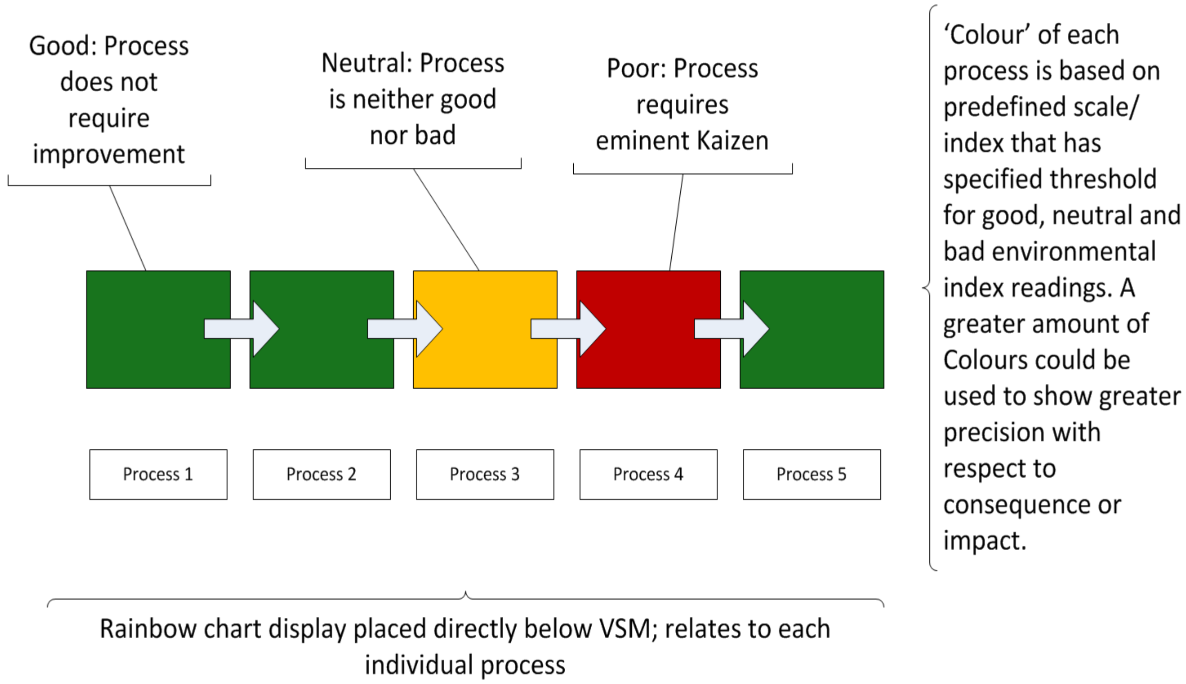


Figure 30: Option 2 - Simplified 'three levels' process flow chart with representation of environmental waste impact. (T. Roosen illustration)

7.7.3 Pipe concept

The third proposed option is a representative pipe concept which would display each process as a series of off shoots from a main 'system pipe'. The width and height of the off shoot branches would be used to show the volume and environmental impact of each stage in the system. The height of the pipe would relate to the risk or impact of that process. The width of the pipe could be used to relate to the volume or amount of waste with respect to the appropriate process. The width of the pipes could also be used to convey the amount of error associated with each process in lieu of the amount of waste. Processes that require Kaizen events would be identified by determining which pipes were the widest and or tallest when compared to each other. A supplementary algorithm could also be used to determine an appropriate index number to compare tall and wide pipes and verify which has greater impact or perceived error. The pipe approach and relating process would then be coloured according to the chosen index or scale to help choose which process to apply the environmental impact reduction initiatives.

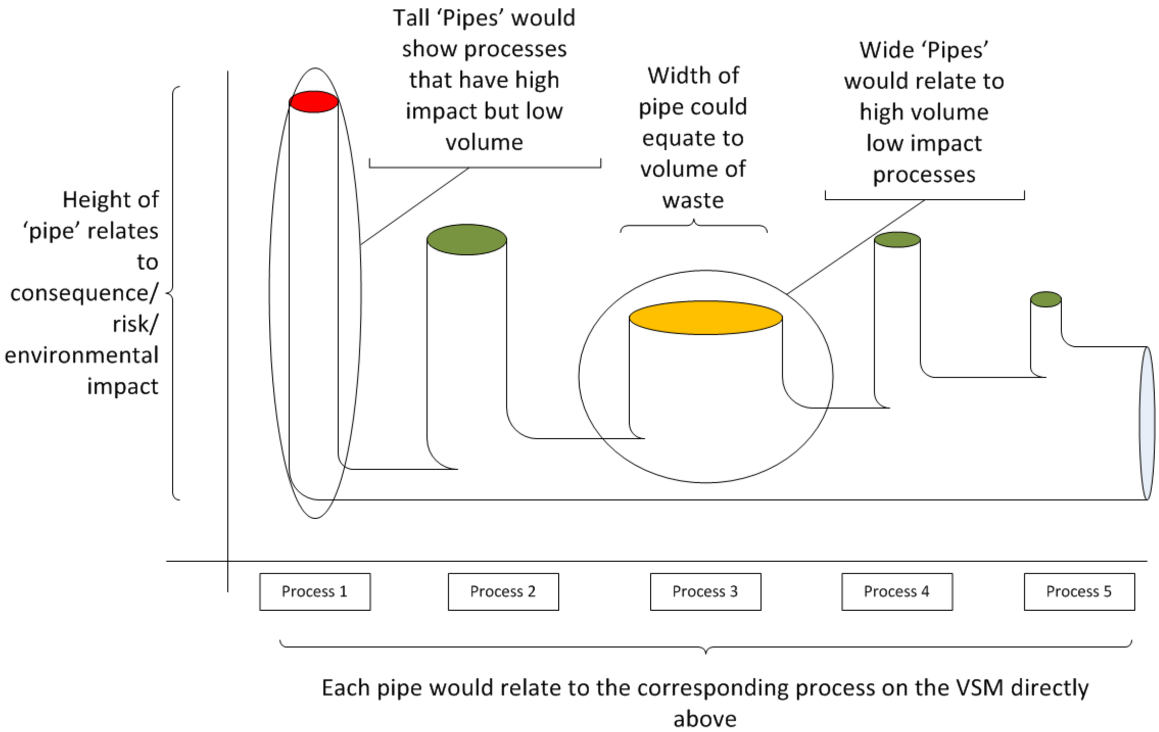


Figure 31: Option 3 - Waste pipe concept to help identify Kaizen events needed with respect to environmental waste impact. (T. Roosen illustration)

7.7.4 Representative symbol concept

The fourth visual representation idea uses a far more simplistic approach than the previous designs. An algorithm would be used to determine the rating of each process with respect to the chosen criteria. Then an appropriate number of waste symbols would be applied to the respect process. As an example of this symbol map, one 'negative' waste symbol would be applied to a process with a low environmental impact and the maximum number of five symbols would be applied to a process that has a high environmental impact (Figure 32). This process could also be applied to the error associated with each stage of the VSM. High error processes would have a greater number of associated symbols and low error processes could have low or no waste symbols. The symbol itself is an important part of the representation of the environmental impact assessment. Careful consideration and feedback of employee responses to the chosen symbols could be used to determine which symbols are most appropriate. Use of the symbols such as skull and cross-bones, rubbish and toxic waste could be directly representative of the environmental impact; whilst an earth or recycle symbol could be used to evoke a more positive response to the waste reduction initiative.

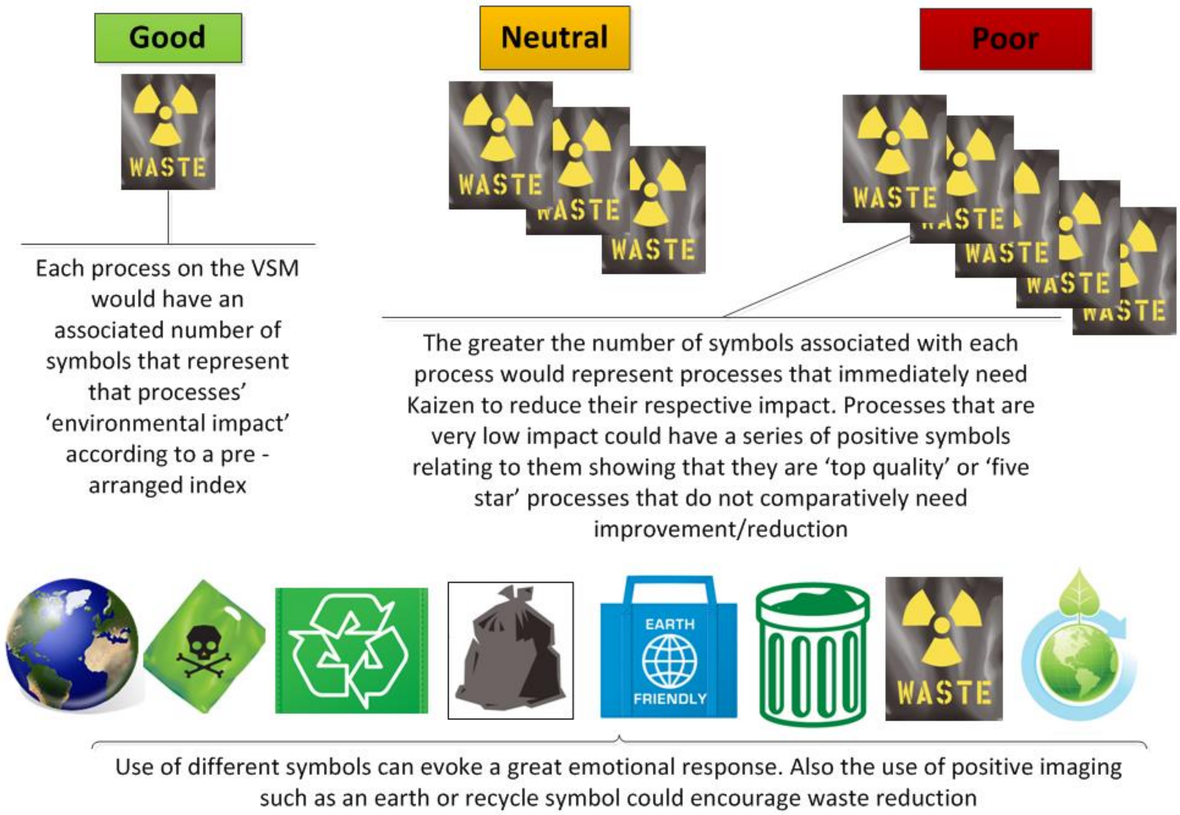


Figure 32: Option 4, Simple symbols attached to each process to show a respective process' environmental impact or waste performance, thus allowing easy identification of processes requiring Kaizen. (T. Roosen illustration)

An extra dimension to the symbolic representation could be the addition of different specific symbols to specify a certain waste, so that those working through the Kaizen event would be able to determine what waste types are associated with each process. However, this addition has the potential to create confusion between the conveyance of waste goals and the additional direct symbolic representation of waste types detracting from the purpose of the Kaizen waste reduction initiatives.

7.8 Evaluation of visual representation

7.8.1 Visual representation evaluation against design considerations

The initial visual representation design phase of the project was to create and evaluate a series of possible representative displays for the chosen index. Four representations were created to show high and low environmental impact processes. A simplified evaluation matrix was used to determine which of the visual displays adhered to the initial design considerations outlined in Section 7.4. A table was created to compare the four visual designs to the initial design considerations.

Table 9: Initial visual evaluation table using primary design considerations

		Visual system			
Category	**Weight**	*Bar Graph*	*Process chart*	*Pipe diagram*	*Symbol use*
Ability to integrate with standard VSM	*5*	5	5	2.5	5
Clear and effective communication process that require Kaizen (waste reduction)	*10*	10	10	5	5
Clear and effective display of data	*10*	7	10	5	5
Ability to display multiple dimensions of waste	*15*	15	10	10	1
Time required to create	*5*	0	2.5	0	5
Ease of use	*10*	5	7.5	5	10
SUM	*55*	42	45	27.5	31
Percent of maximum score	-	76%	81%	50%	56%

The matrix showed that the proposed pipe concept was the least favourable option whilst the simple bar graph, process chart and symbol concepts all scored above 55%, as shown in Table 9. The simple bar graph has several key benefits and detriments. The first disadvantage of the bar graph concept is the lack in ability to be produced quickly. It must be drawn by hand during the VSM event. This could be considered a severe disadvantage if the environmental assessment has to occur in conjunction or simultaneously with the VSM event and must be drawn by hand. A possible solution would be to ensure that a computer and projector are provided when running the environmental assessment of the VSM in question. This would ensure that the graph could be displayed alongside the current and future state maps. However, another disadvantage to the graph concept is the higher complexity level and needed technical skills for creating the graph, coloured bars and error bars.

One of the main advantages of the bar graph concept is the ability to show inaccuracy of results inherent in specific processes. This is a very important aspect when dealing with waste as processes. Some of the data can be very inaccurate and misleading, while in reality a process could be considered extremely wasteful and have the potential to be the largest contributor to the overall identified wastes. Another benefit of the bar graph concept is the addition of coloured columns to help highlight processes that reach a pre-determined waste impact threshold allowing high impact stages to be easily identified.

The primary advantage of the rainbow flow chart model is the ability to very swiftly distinguish high and low environmental impact processes, as well as its ability to be used simultaneously during a VSM event. The main disadvantage of the rainbow chart is the inability to visually show accuracy of results. A possible solution for this would be to include a pre-determined accuracy or error weighting to be included in the overall environmental index aggregate.

The third representative of a pipe model has several drawbacks and benefits. The pipe concept is effectively a stylised version of the graph model in which a pipe is used to invoke an emotional response. One detriment of the pipe concept is the confusion that might ensue when trying to draw the pipes to scale to show the largest environmental impact process. The pipe display is also limited to a similar extent as the graph example with even a slightly more complex technical drawing of pipes required. In addition the drawing of the pipes is difficult in determining an appropriate scale and axis.

The final representative symbol model is the simplest representation of waste with respect to processes. The simplicity of the model is one of the largest advantages. This allows people of any skill level to add, remove and change the number of symbols associated with each process. Another advantage of the symbol model is the ability to be used at any point throughout the VSM process. One of the biggest detriments of the symbol representation is the lack in accuracy in reflecting comparison waste amounts, as well as the lack in showing actual data or error for data collection. Again, the solution for this could be to form a weighted index that takes into account error. This would allow the final aggregated index to reflect high and low error processes. Whilst simplistic in use and effective in display, this model relies upon the index aggregate to take into account all waste factors, error of results and an appropriate threshold creation to determine the appropriate number of symbols for each process.

7.8.2 Initial sponsor focus group - review of initial visual depiction and indices

To ensure the development of the environmental impact assessment tool aligned with the goals, requirements and specifications of the CEC, a series of focus review sessions were created. Attendees included personnel from the appropriate business groups that would actuallty use the environmental index at the CEC. These were primarily leaders from Engineering, Environmental Health and Safety (EH&S) and the Achieving Competitive Excellence (ACE) section. The attendees helped further define the system boundaries, determine the extent of the visual representation and help clarify which index would be most suited to CEC's organisational purpose and goals. The primary purpose of the first focus review was to determine which visual representation of environmental waste and which composite index would be most suited for use at the CEC. The focus group first looked at the review of the proposed visual displays of waste shown in Figure 29, Figure 30, Figure 31 and Figure 32. Several key outcomes were determined for both the visual display and index creation as a result of the focus group discussions.

The first topic covered in the focus group review session was the method in which the visual display would integrate the composite index with the current value stream mapping. After a review of the four visual options, it was decided to reduce the visual complexity with an integrated approach allowing the proposed process display to sit alongside the current VSM data box. It was suggested that the waste analysis tool could be summarised as a single supplementary data entry point into the existing VSM data box, thus reducing visual clutter. Along with the addition of the environmental impact index for each process to the current data box, it was decided that the rainbow flow chart be included into the display. The rainbow chart concept was used to reflect if a process was “good”, “poor” or “neutral” according to a predetermined threshold and boundary system. Adjusting the colour of the process data box was deemed an effective way to visually highlight the environmental impact of each process in addition to the extra environmental impact data entry.

After the discussion on the visual representation, the various index options were also reviewed. The most favourable index (by general consensus) was a customizable index that would allow the user to modify the scale based on current site objectives and organisational purpose. A custom scale was also deemed the most preferred option because it allowed a balance to be created between:

- accuracy of results
- an adjustability of the index
- adaptability of the applied method to demonstrate high environmental impact processes.

An important specification (from the focus group’s point of view) was for the composite index to be customisable enough to allow for future modifications as a result of changes from organisational purpose of site goals. This essentially future-proofed the methodology and index. The index was also required to be flexible in terms of using existing data or it needed to be cross-compatible with data that could be collected easily. Possible custom factors to be used in the composite index included:

- volume
- carbon footprint (taking into account both power used and power sources)
- input cost (cost of input as related to toxicity)
- toxicity
- perceived impact
- energy (just a power measurement)
- remediation ability
- cost of cleanup.

A final discussion was held as to whether data in the environmental impact index would be summed or averaged over the entire system. A decision was made to sum each process index together thus allowing a comparison to be made from one set of processes to another; as well as current state VSMs to future state VSMs.

7.8.3 Secondary sponsor focus group - reviewing factors and composite index

Following this, a further industrial practitioner focus-group held a review session with leaders in the Environment Health and Safety (EH&S), lean and VSM (Value stream mapping) groups. From this focus group, a final customised index was proposed which incorporated aspects of the described standards and index developed from the first focus group as found in Section 7.8.2. The second focus group agreed with the customised scale for the same reasons of accuracy of results, adjustability of index and ability to highlight high environmental waste impact process. Like the first focus group, an important specification outlined was for the composite index to be customisable enough to allow for future modifications from changes in the organisational purpose of site goals. A selection of five environmental factors was selected that reflected the strategic goals and organisational purpose of the particular industrial application. The chosen set of environmental factors for this application was:

- carbon footprint
- perceived impact of waste [levels 1- 10]:
    - **Level 1:** relates to near zero or minimal perceived human impact (such as organic waste and stormwater)
    - **Level 5:** relates to medium level of perceived human impact (such as sewage)
    - **Level 10:** relates to a very high perceived impact on humans (such as anthrax, radiation or asbestos.
- cost of cleanup/remediation per kg
- removed waste volume x Site Environmental Risk Register value (Based on ISO14001 standards)
- remaining waste volume x Site Environmental Risk Register value (Based on ISO14001 standards)

These cover all the factors that the focus group deemed pertinent to the site. However, the method is able to accommodate different factors and different numbers. Thus, practitioners can focus on the factors appropriate in their own situation rather than merely adopting the above list. An important aspect to note is the replacement of the 'toxicity' aspect with the use of a CEC risk register. A toxicity scale using LD_{50} or $C_{90,}$ was deemed too variable due to the inconsistency in which toxicity data was captured. In addition there is the inability to cover every type of production process due to incomplete data sets with regards to the toxicity scales. Initially Hazardous Substances and New Organisms (HAZ-NO) data sheets (from the HAZ-NO Act 1996) were investigated as a substitute measure of equivalent toxicity. However, no single value could be found to provide an indication of toxicity or equivalent measure.

In lieu of toxicity, the CEC Risk Register (based on ISO 14001 standards) was chosen, as it provided a singular value for each process and was used site-wide so it would therefore have a value for every process. The risk register was also determined to be suitable due to its ability to take into account broader aspects other than just toxic impacts. The Risk Register provides a more holistic environmental impact measure, taking into account aspects of the organisation and the interaction with the environment. This register covers toxicity by default by evaluating the 'risk' of each process against a common scale. The Risk Register primarily has three levels listed as:

- normal
- abnormal
- emergency values.

The normal level was chosen for the purpose of this project. A secondary environmental factor was also added to cover the disparity between processes which might have a large amount of low risk waste removed, compared to processes which might have waste or chemicals physically removed at one point, but use highly toxic or high risk chemicals throughout operation.

Finally, the initial proposed methodology required a target to be determined to help compare a process' performance. However, this was determined too complex to try and estimate. Thus a percent-based threshold was used instead and this described in the following section.

7.8.4 Synopsis of focus review sessions

A summary of the conclusions from the two formal focus review sessions is as follows:

- The process map visual representation idea would be incorporated into current VSM use.
- Colour integration for each process data box would represent a level of the environmental impact index which was to be incorporated.
- A custom index was chosen.
- A preliminary selection of factors was made which was to be formalised in further review sessions.
- A 'change target' or value estimation feature would reflect the target percent threshold of total waste/Environmental Index Factor.
- The waste-removed category was modified into two categories. The first category represented waste remaining at a process location. The second category represented waste removed from the process.
- The toxicity factor was removed with a replacement of Risk Register values. This would take into account a more holistic environmental impact, as well as aspects of toxicity. A decision was made to remove toxicity due to its high results variability. The 'Normal' risk register values would be used in the index.

The next step was to act on the results from the evaluation and focus review groups and develop a composite index.

7.9 Creation of composite index

Creating a composite index consisted of several key stages:

- the initial environmental index factors (EIF) estimation
- determination of an average EIF
- aggregation of the final EIF.

This overall process is shown in stages with Figure 33, Figure 34, Figure 35 and Figure 36. An excel spreadsheet was used to create and display the index. For this example of five environmental factors, the final illustration that resulted was similar to a radar chart display. The aggregation of the composite index started with the definition of the chosen environmental impact factors (EIF). It was planned that these interchangeable factors would be the foundation which the final Environmental Impact Index (EII) will be based. Thus, they were selected carefully to reflect the organisational purpose, goals, and environmental aims of the organisation as indicated in Figure 33.

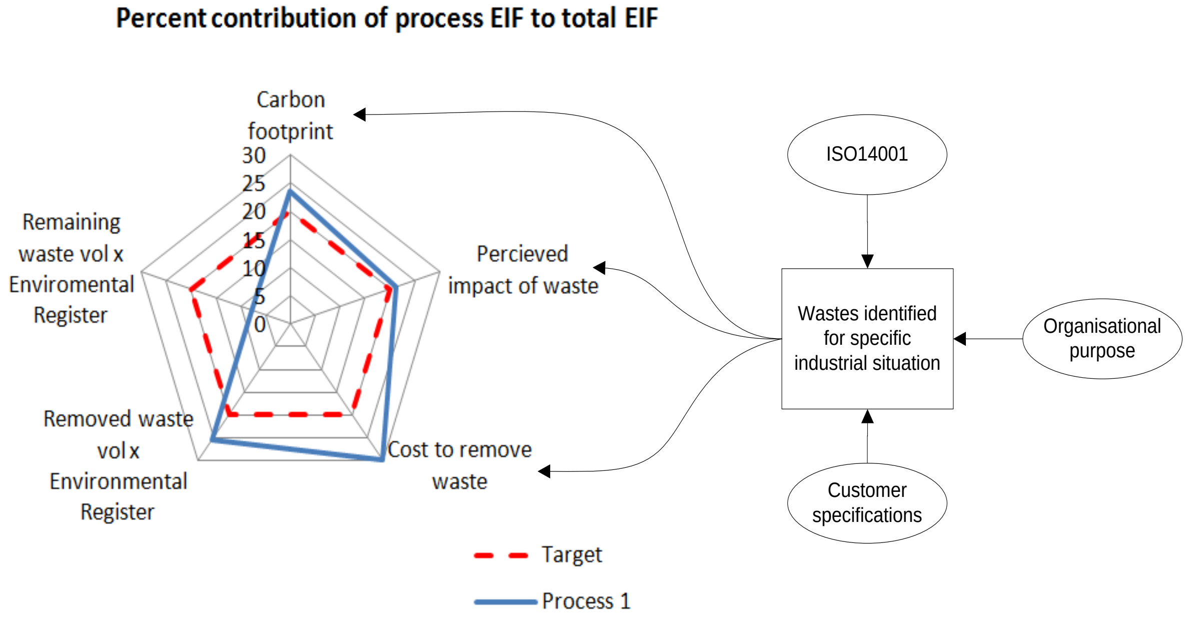


Figure 33: Representative illustration of initial Environmental Impact Factors (EIF) considered and subsequent pentagon or radar chart resulting for a single process in the value stream. (T. Roosen illustration)

After the chosen factors for this particular application at the CEC were decided (Section 7.8.3), the second aspect that required definition was the scaling factor (SF). This element allows a layered system approach to be undertaken when determining which EIF was the most important from a customer, practitioner or manufacturing perspective. This pre-weighting also allowed compensation to be made for low-valued EIF units. Under normal circumstances, the scaling factor would remain 1, unless a specific EIF needed to be highlighted or targeted. If a larger scaling factor was required, the practitioners were advised to increase the scaling factor in increments of 10 until a suitable value was reached. This reduced the complexity of determining an appropriate number. This scaling factor was used as an alignment modification to reduce or enlarge the importance of any of the chosen EIFs. The scaling factor could also be useful to reflect a changing organisational strategic purpose; for example placing a greater importance on a carbon footprint. So by increasing the scaling factor of the carbon footprint aspect, the company would effectively increase the percent contribution of that environmental index factor to the overall index. Importantly, the production improvement processes inherent in the lean systems would automatically refocus to reduce this particular waste.

Once the appropriate EIFs were selected, the data collection for each EIF could proceed. To compensate for inaccurate, incomplete or estimated data collection of EIF, a PERT analysis weighting (based on a three point estimation) was used to determine an average EIF value. This is shown in equation 1 below. This equation results from fitting a beta probability distribution to three estimates, as shown by Figure 34. The EIF values are separated into Pessimistic (P), Expected (E) and Optimistic (O) values. The distribution is weighted towards the expected EIF value to minimise extreme data outliers, such as an overly optimistic or pessimistic evaluation.

Equation 1 $$EIF\ estimated = (O + 4E + P)/6$$

Equation 2 $$EII\ (vector\ magnitude) = \sqrt{(EIF_1 * SF_1) + (EIF_2 * SF_2) + \cdots + (EIF_n * SF_n)}$$

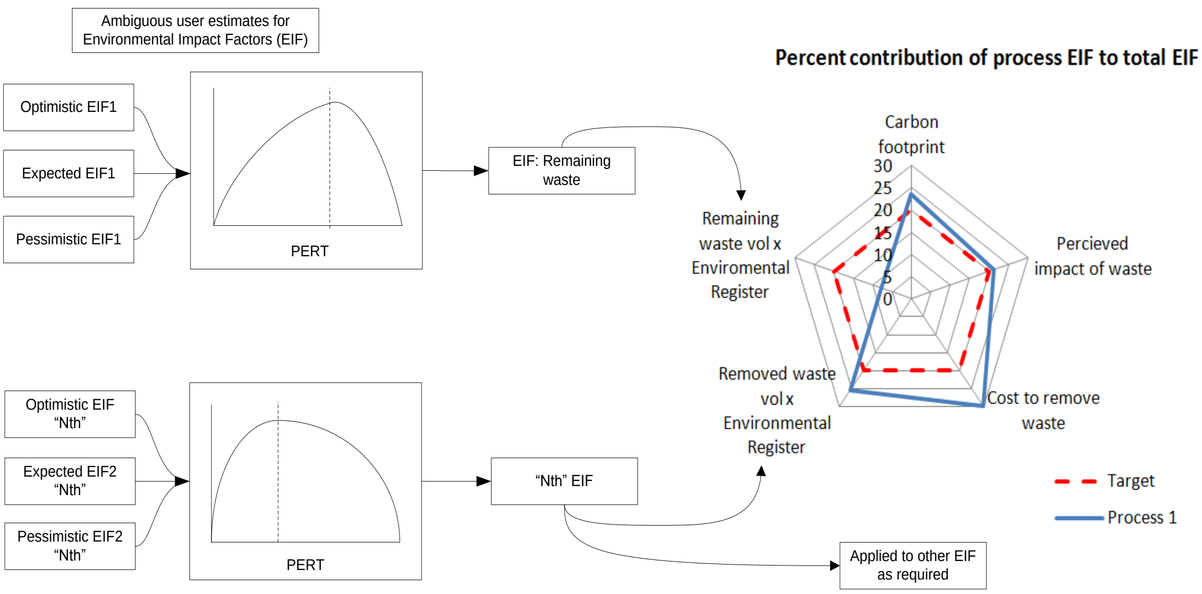


Figure 34: Method of determination for each Environmental Index Factor (EIF) value using a PERT estimation. (T. Roosen illustration)

After the mean EIF value is determined using the PERT analysis, (as illustrated in Figure 34), the EIF is then multiplied by a scaling factor (SF) as described previously. The next stage in aggregation of the composite index is to assimilate the various EIFs into a single index. This is determined by adding the vector magnitude of each EIF together, shown by Equations 1 and 2, as well as Figure 35. There are several reasons for using a vector magnitude to determine the final EII. The first reason relates to the theoretical modelling used to address the problem and create a suitable solution. The approach used was to examine if the application of risk analysis or risk matrix and consequence scales (which often represent environmental risk) could be used to provide a single valued solution. This concept of a risk matrix was replaced by a model in which the x and y axis described the EIF characteristic of a carbon footprint and the volume of waste for a specific process. This model was further expanded to include a greater number of axes that represented different and yet appropriate EIF. The end result was the creation of an n^{th} dimensional model that could be used to describe any number of EIFs. Finally, a five dimensional model was chosen, with each EIF being represented by a separate axis. Each process could then be mapped in accordance to the contribution of an EIF, represented by a separate axis. This resulted in a representative 5 dimensional vector for each process. An example of a three dimensional illustration using only three environmental impact factors is shown by a simplified diagram in Figure 35. The vectors describing each process could then be consolidated into a single valued unit through the use of the vector magnitude equation. This also means that from the addition of any extra 'dimensions' describing a different EIF, a final solution can be easily adjusted by adding in another vector component.

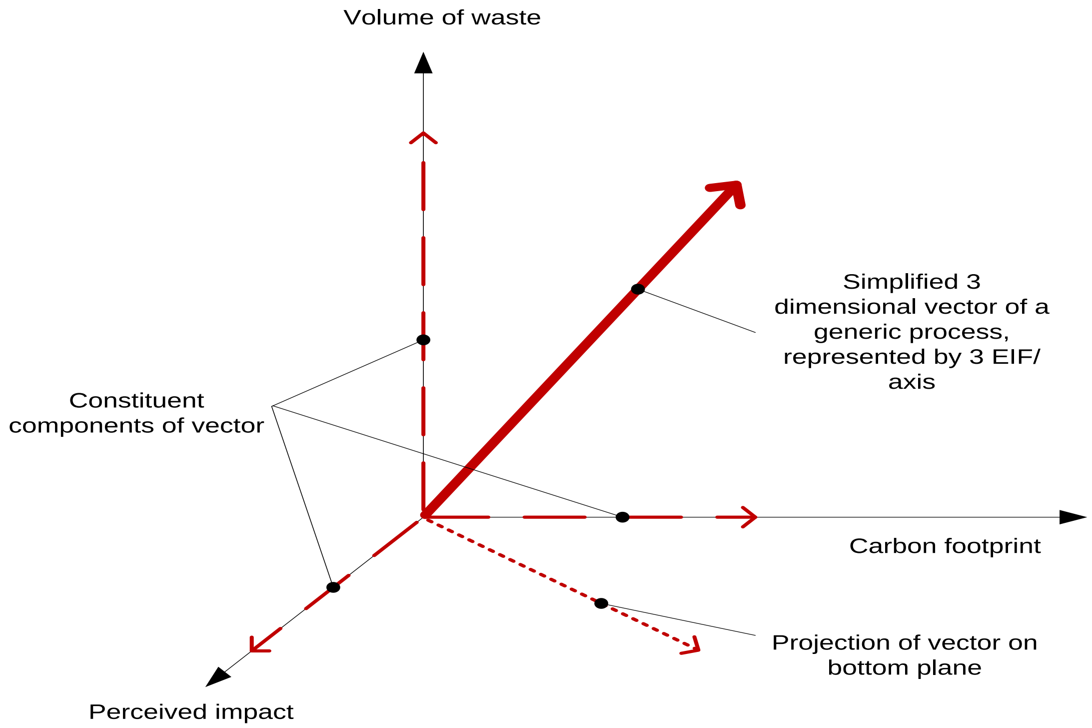


Figure 35: Simplified three dimensional vector representation of a generic process using three representative Environmental Impact Factors (EIF). (T. Roosen illustration)

The second supporting rationale for using a vector magnitude, relates to the inability to simply multiply or add the EIF together. Direct multiplication or addition of the chosen EIF is not recommended. This could result in a large number valued solution for specific processes as a result of one particularly high EIF that could skew the results. This problem is solved by using the vector magnitude equation, as well as incorporating a scaling factor in the magnitude equation to ensure no single EIF or process dominates the overall analysis. Thirdly, the vector magnitude approach allows for the likely event of a specific process having a zero-valued EIF. If multiplication was used, then the final value representing a process with a zero-valued EIF would be reduced to zero, and would reflect an inaccurate result. The vector approach allows for any number of EIFs to be zero-valued and still provide results in a final indicative environmental impact index. Finally, addition of EIFs were considered using a possible aggregation method. However, due to both large numbers dominance of some EIFs compared to others, as well as unit mismatch, this was discarded in favour of the vector approach. This methodology is able to accommodate any number of types of waste, and thus we refer to this as an n^{th} dimensional concept. The illustrated model uses five waste dimensions. Each of these is represented on one axis and additional axes may be added as further wastes are included. The vector magnitude then reduces the n^{th} dimensional representation to a single value. Obtaining a single value allows the practitioner to report summary data to managers and superiors, and hence indicate how well the plant is meeting its strategic environmental objectives. Thus, the method integrates well with strategic management initiatives at the one level, as well as lean improvement (via VSM specifically) at the operational level.

Once the EIFs have been summed into a single environmental impact index (EII) a series of radar charts can be created to help display the process' individual performance and overall system performance. Radar charts and conditional formatting are used as an effective way to help identify which processes require Kaizen initiatives. The radar charts are used in two ways. The first radar chart (B in Figure 36) is a summary figure which displays overall performance of each process compared to the high and low percent target thresholds. The thresholds are analogous to the upper and lower control limits of a run chart, allowing a user to identify when the process is behaving poorly (outside the bounds of the target threshol) or well (within the bounds of the target threshold).

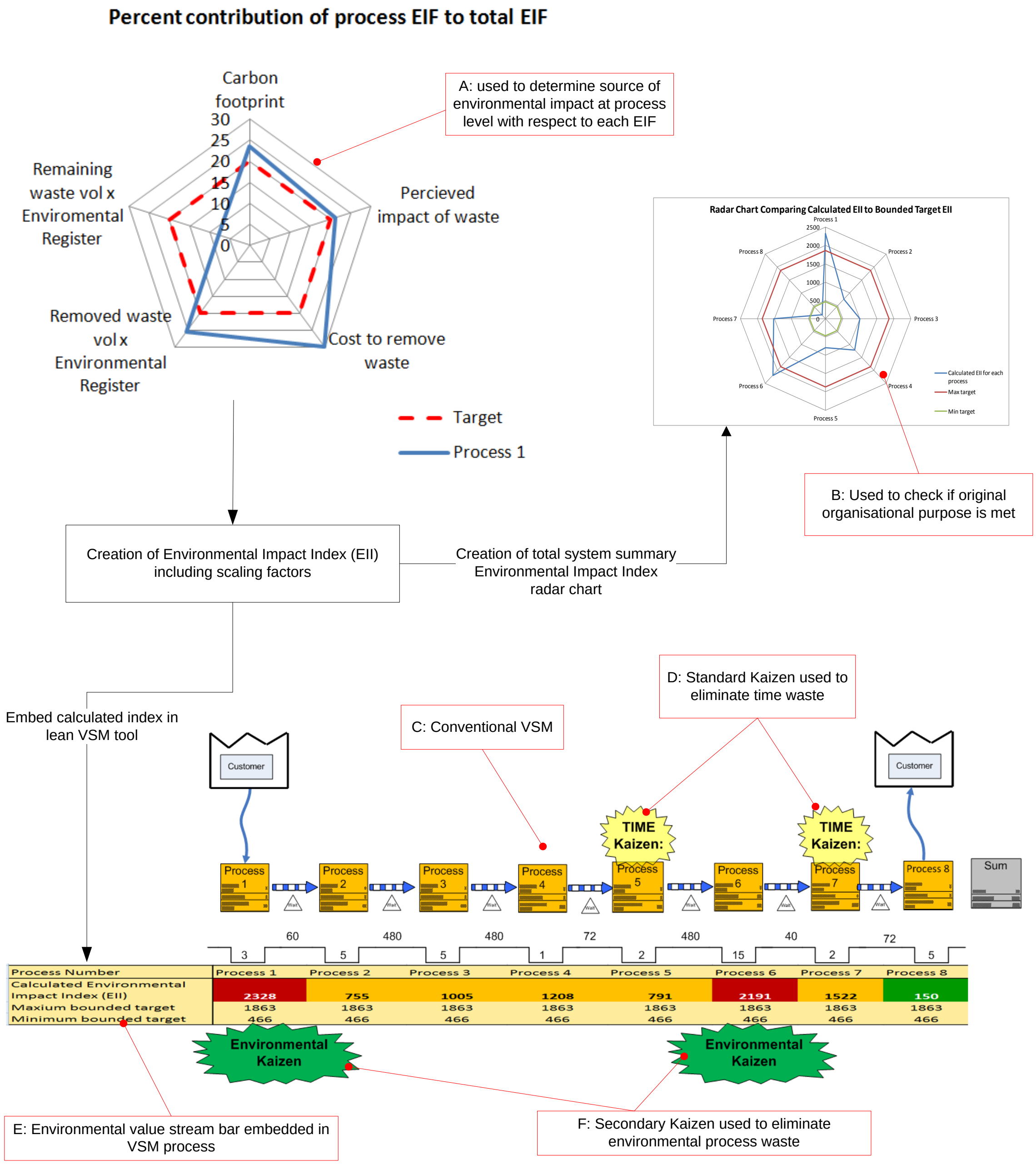


Figure 36: Displays the method in which final EII is aggregated from EIF data (A and B), the conventional time value stream (C and D), how the EII are incorporated into VSM (E) and the resulting environmental Kaizen created (F). (T. Roosen illustration)

The high percent threshold is determined by reducing the highest calculated EII by the top percent target, whilst the low threshold is determined by multiplying the highest calculated EII by the low percent target. These percents are then used across the entire system to determine good, neutral and poor performing processes. In this case study, the high and low targets are determined by multiplying the highest calculated EII by 80%, whilst the low threshold is determined by multiplying the highest EII by 20%. This is shown in Figure 37 and

Figure 38 by the red and green lines respectively. Any process above the maximum threshold in the summary radar chart can be described as a critical process requiring Kaizen activities to reduce the overall environmental impact value. Conditional formatting has been used to set the displayed summary process environmental impact index to red to reflect the poor performance if the results is above the maximum threshold. Processes that are between the thresholds are ones that do not require immediate attention, but have the potential to be a large environmental impact over the next few EVSM iterations. These are set to yield a 'yellow' result. Finally, processes below the minimum threshold are set to a green showing that they will most likely not require intervention. The percent approach used is to multiply the maximum calculated environmental impact index for the system in question by a maximum and minimum percent threshold.

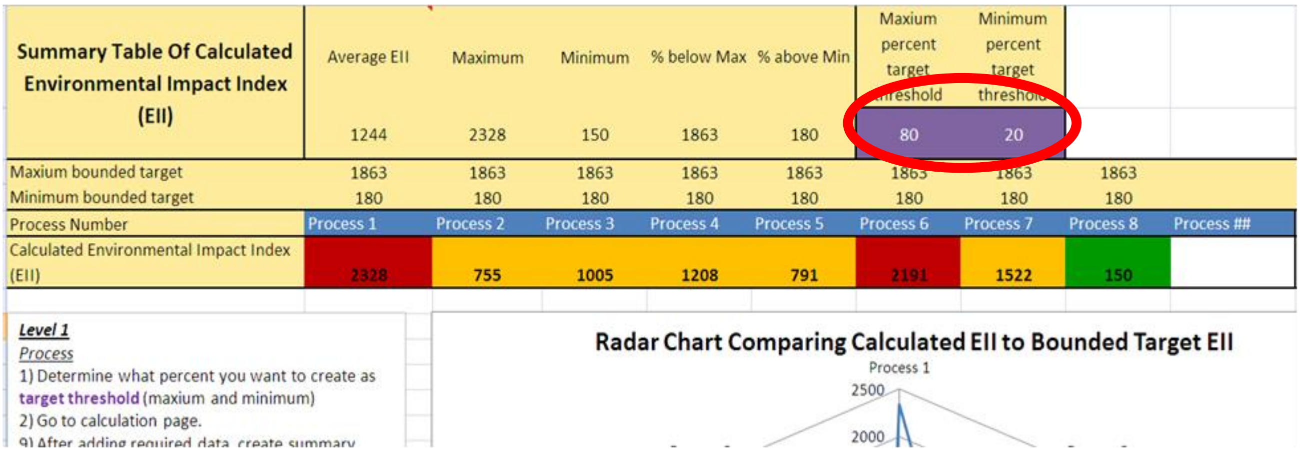


Figure 37: Maximum and minimum percent threshold of system. (T. Roosen illustration)

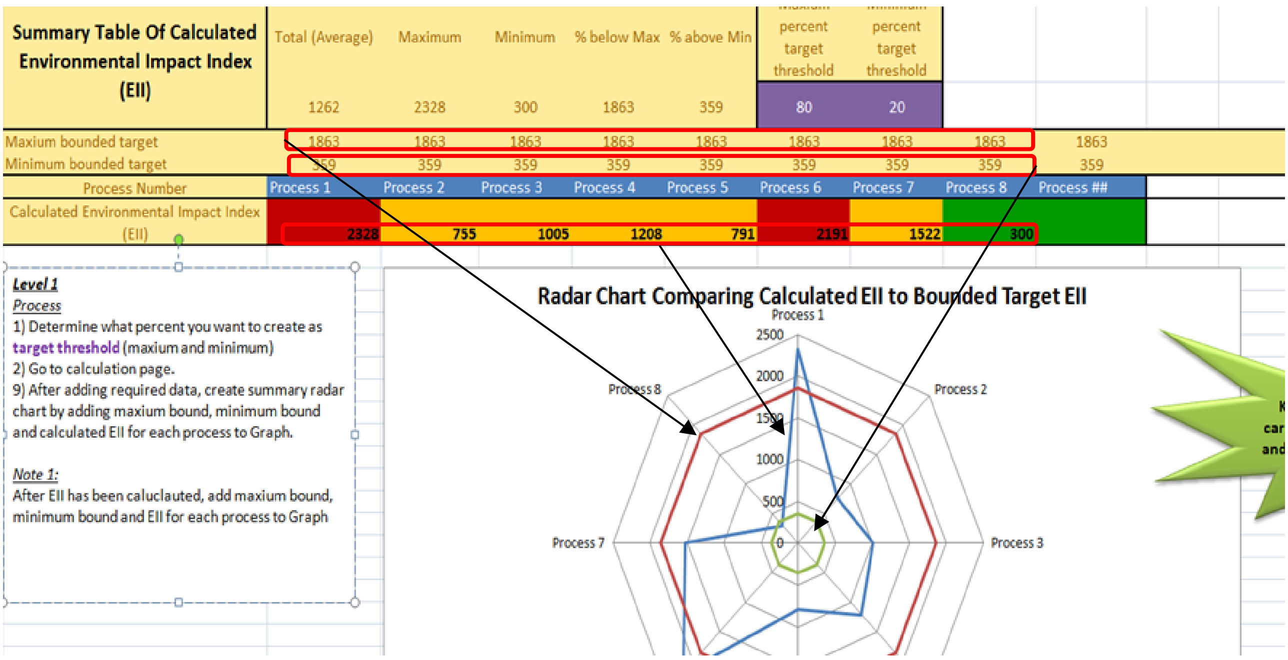


Figure 38: Representation of high and low threshold bounded targets shown by red and green lines respectively. These are compared to the actual process results shown by a blue line. (T. Roosen illustration)

These percents are then used across the entire system to determine good, neutral and poor performing processes. Any process above the maximum threshold in the summary radar chart can be described as a critical process requiring Kaizen activities to reduce the overall environmental impact index value. Conditional formatting has been used to set the displayed summary process on the index to red to reflect the poor index performance if above the maximum threshold. Processes that are between the thresholds are the ones that do not require immediate attention but have the potential to be large environmental impacts over the next few years. These Environmental Value Stream Mapping (EVSM) iterations are subsequently set to yellow. Finally, processes below the minimum threshold are set to green showing that they will not require Kaizen initiatives over the next several iterations of the EVSM tool. This is shown in Figure 39.

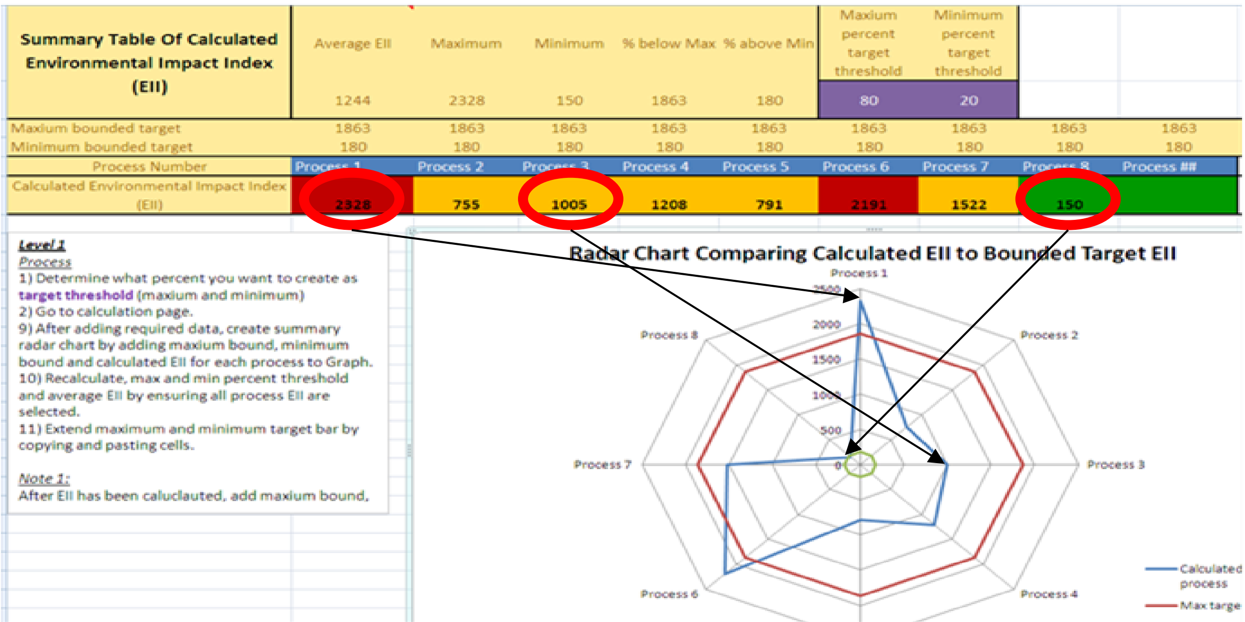


Figure 39: Rainbow chart display of red, yellow and green representative processes of bad, ok and good performing EII in the summary EVSM page. (T. Roosen illustration)

Secondly, the radar chart is used is to display a breakdown of each process performance with respect to the chosen EIF. The first step is to determine the sum of the total system environmental index factors. Each process radar chart is then created by determining the percent contribution of a particular process EIF to the total system EIF of that system. This is shown in Figure 40. The practitioner can then easily compare and identify which environmental factor and what particular process requires Kaizen implementation, as shown in Figure 41. Once the practitioner has determined which process (and subsequently which EIF) contributes most to the highest environmental impact index, an environmental kaizen can be created (e.g. use of a Green Kaizen star) shown in Figure 41.

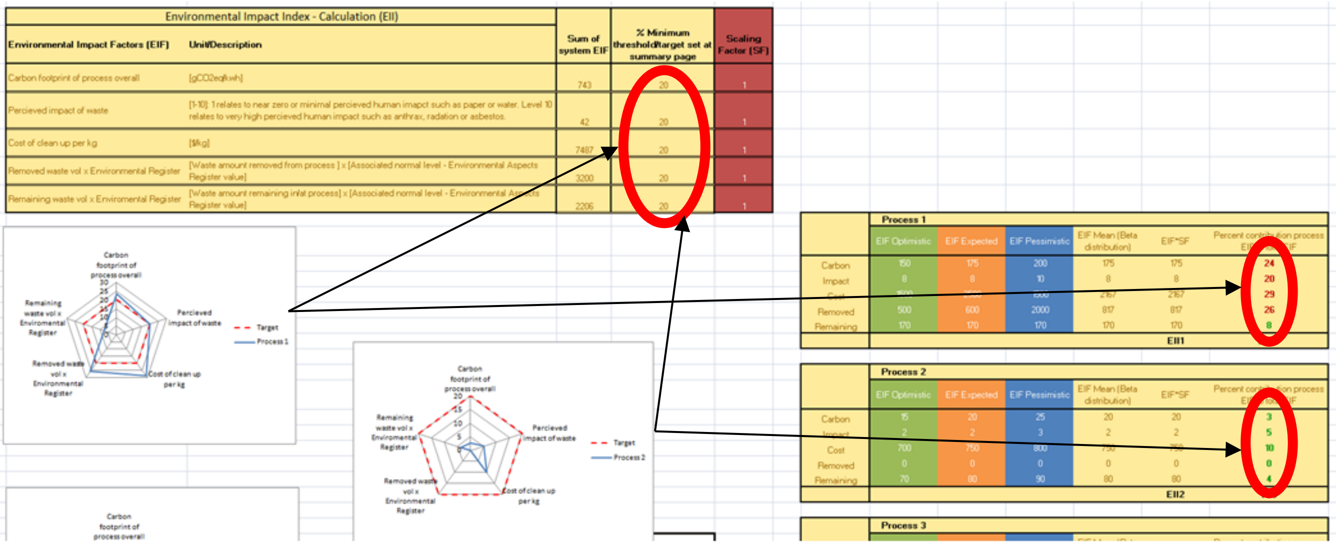


Figure 40: Individual process radar charts displaying percent contribution of each environmental impact factor (EIF). (T. Roosen illustration)

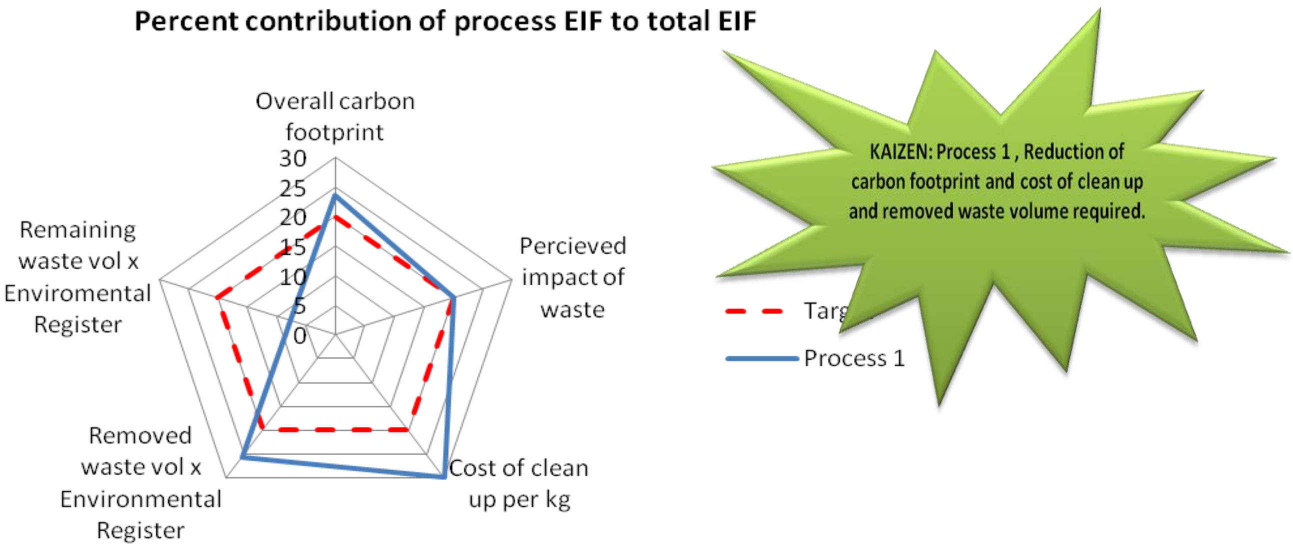


Figure 41: Representative process EIF comparison radar chart along with associated Kaizen which has been identified for Process 1. (T. Roosen illustration)

This environmental Kaizen creation stage is the key vertical alignment factor that links overall site organisational data to the processes where the waste is generated. This is one of the failing noted in the introductory chapter and displayed in Figure 1. The final aspect of the index incorporation is the inclusion and transfer of the summary environmental impact index data onto the standard VSM templates, thus creating the final EVSM product. An example representative EVSM is shown by C in Figure 36, along with the incorporation methodology. The figure shows a simplified standard value stream (yellow data boxes), standard 'time' domain Kaizen and associated lead time ladder. Below the lead time ladder is the summary environmental impact index information and the associated environmental Kaizen (green Kaizen). The figure also demonstrates the key value added product which is the primary environmental value stream embedded into the VSM. This is included along with the creation of environmental Kaizen from the system analysis.

7.10 Summary

This chapter examined the primary components for the creation of an environmental Value Stream Mapping (VSM) impact index. This section reviewed possible indices along with visual representations of the index which could be incorporated with VSM use. A final visual representation and index aggregation method were chosen through the use of two practitioner-based focus group review sessions at the CEC. A final composite index was chosen that uses a number of environmental impact factors to fully represent the environmental impact of a chosen process. These factors can then be amalgamated into a composite index and compiled into a user-friendly tool which is comprehensive. The entire development of the index uses an excel spreadsheet for creation of the tool. The visual representation of the index was refined over time. It is defined as a simple process flow chart with the environmental impact ladder displayed below the lead time ladder on a standard VSM to reduce the index application complexity. The overall index creation and incorporation methodology was combined into a standard operating procedure (See Appendix C: Standard operating procedure for environmental impact index) using the previously created lean change management model. This was implemented at the CEC as described in the next chapter.

8 Test and validation: trial implementation of EVSM method at Christchurch Engine Centre

8.1 Introduction

This chapter looks at applying the created environmental impact index (EII) methodology. The application was tested at the Christchurch Engine Centre to determine the effectiveness of the chosen system. In addition the test looked at usability from the practitioner's point of view and what future modifications might be investigated to improve performance.

8.2 Application of methodology for the environmental impact index

The initial application of the environmental impact index was on a repair and operations set of processes, specifically the future state map of the Annulus Repair procedure. This particular VSM was a future state value stream map in which the environmental impact index was applied in retrospect. The VSM consisted of nine processes describing the repair stages required for the Annulus Filler, as shown in Figure 42.

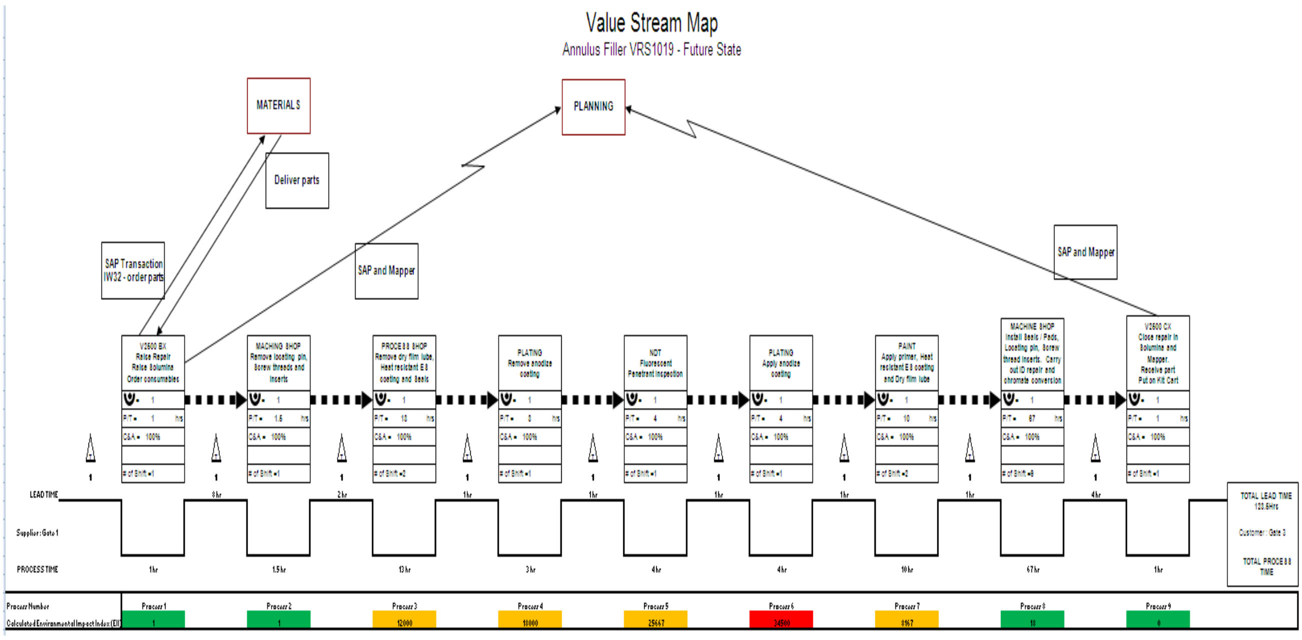


Figure 42: Implemented Environmental Impact Index incorporated with VSM for the Annulus Filler process (An A-4 size figure is in Appendix F)

The implementation began with a tutorial of how the environmental impact analysis methodology worked and how it was integrated with VSM use. This tutorial was based on the Standard operating procedure (SOP) for the environmntal impact index outlined in Appendix C. Using the lessons learned from the change management review, the selected practitioners were informed of the new methodology through the use of the previously developed change management model and the SOP.

After notification, the index implementation and evaluation began. The evaluation started with a review of the Annulus Filler VSM process to ensure all participants understood each stage of the process. Once all participants were informed of the overall approach of the environmental index method and its relationship to VSM, the first stage of the analysis was instigated.

The first stage for the test application, as outlined in Section 7.9, was to determine the overall percent target threshold and scaling factors. For this first implementation, a maximum target was set as an 80% reduction of the highest index value, whilst the lowest threshold was set as 20% of the maximum index value calculated. The next stage was to start filling in the required environmental impact data box entry information. The data information that was necessary is listed in the following bullet points:

- Carbon footprint data, including any and all forms of power use (computers, lights, equipment), any boiler or heater use and any transportation. Each process was examined and the carbon footprint for each component of the process was summed to determine a final value. This stage occasionally required visits to the process locations to determine power consumption or equipment use, thereby allowing the carbon footprint to be accurately determined.
- The perceived impact was determined for each process; using the pre-determined scale from the focus group review.
- The cost to remove waste was determined or estimated as a component of municipal waste removed from each set process which made up the selected value stream.
- The waste removed from each process stage of the value stream was then multiplied by the appropriate CEC Risk Register value (CEC Risk Register based on ISO140001)
- The final data collected was the waste remaining at the process location, which is then multiplied by the appropriate Risk Register value.

After the data collection was completed, the excel portion of the index automatically calculates the specific environmental impact for each process and updates all the process radar charts. The excel results then update the visual display of the process summary radar chart. See Figure 43 for the summary chart and Figure 52 through Figure 60 in Appendix E for the process level radar charts used in this test application. Once the summary environmental impact index data bar for the system was updated, it was then be directly transposed onto the VSM being analysed as shown in Figure 42. (A full size version is shown in Appendix F.)

The VSM with the added environmental impact index data bar and summary system radar chart was then analysed along with the process radar charts to determine which process had the highest environmental impact. In addition there was a focus on what component of the Annulus Filler process yielded the biggest contribution to this high environmental impact index. Finally, after all information was captured as required, the environmental value stream ladder was added to the VSM, as well as the

Kaizen events identified. After the test group completed this process, a questionnaire (Appendix D) was used to determine the effectiveness of the environmental impact index methodology. In addition, the change management model (Figure 27) which was used throughout the implementation and described in Section 4.6.1 was evaluated.

8.3 Results of implementation

The initial results show the environmental impact index methodology was particularly effective with respect to the selected key dimensions selected. Further, it enabled vertical integration of the environmental impact with each specific process and integrated this system with all the VSMs. Overall, it increased the practitioners understanding of environmental performance which in inself is extremely valuable to aid in reduction.

Process Number	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7	Process 8	Process 9
Calculated Environmental Impact Index (EII)	**1**	**1**	**12000**	**18000**	**25667**	**34500**	**8167**	**18**	**0**
Maxium bounded target	27600	27600	27600	27600	27600	27600	27600	27600	27600
Minimum bounded target	6900	6900	6900	6900	6900	6900	6900	6900	6900
Percent below or above max target	-99.9%	-99.9%	-56.5%	-34.7%	-7.0%	25.0%	-70.4%	-99.9%	-99.8%

Figure 43: Radar chart and summary system data showing the environmental impact index data from the Annulus Filler analysis.

Upon an initial examination, preliminary results appeared to correlate well with the excepted result of highlighting the environmental impact and performance of these processes, as well as educating staff. From the system summary radar chart and VSM overview, it was relatively easy to observe that process six was the highest environmental impact process primarily due to the combination of:

- its high perceived impact due to the toxic chemicals used
- high cost to remove again due to high toxicity
- waste remaining/risk register value environmental index factor.

As noted, the system summary radar chart is shown in Figure 43, whilst the entire set of process radar charts (Figure 52 to Figure 60) are shown in Appendix E. All the percentages noted in the following paragraphs are indicated in the full details of the process radar charts shown in Appendix. The primary result is the ability of the EII to easily and effectively emphasise high impact with specific processes in contrast to the overall system. Process six is shown to have the highest environmental impact (approximately 25% above the maximum target), as shown in Figure 43. To determine the root cause of this high impact, the practitioner can easily find the process summary radar chart for process six by drilling down through the EII calculator tool. In addition the process radar chart shown in Figure 44, and quickly and effectively shows that process six contributes over 35% (see Process 6, Table 14, Appendix G for percent) of the remaining volume multiplied by the risk register value to the system's total for that environmental index factor.

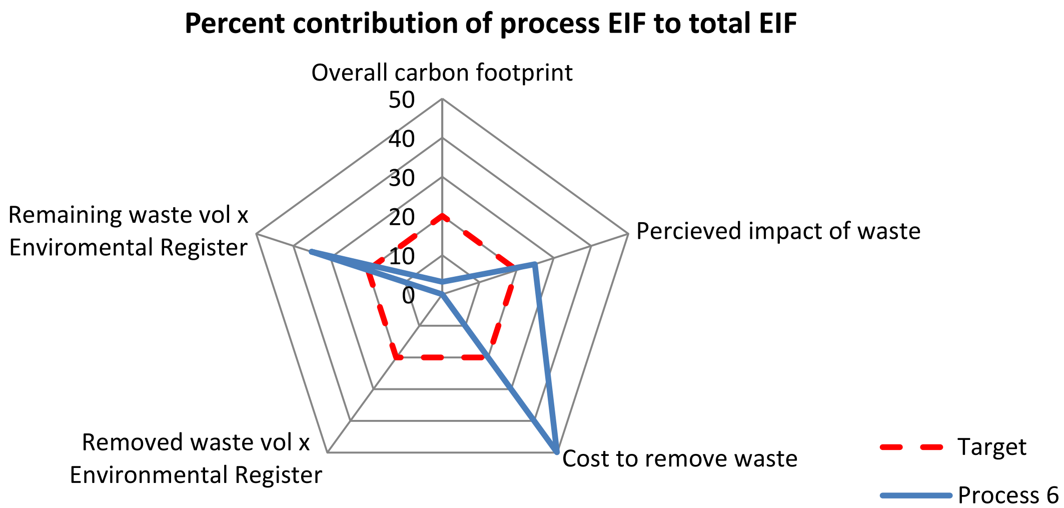


Figure 44: Radar chart of the highest impact index displaying percent contribution of each environmental impact factor to the total system environmental impact factors.

Thus Process 6 also contributes nearly 50% of the cost for waste removal (Process 6, Table 14, Appendix G) of the system's total. The radar chart also shows that process six has a high perceived impact rating. It contributes 25% to the system's total perceived impact rating (Process 6, Table 14,

Appendix G). From this information, the first environmental Kaizen event relating to process six's elevated environmental index factors can be created as shown by Figure 45.

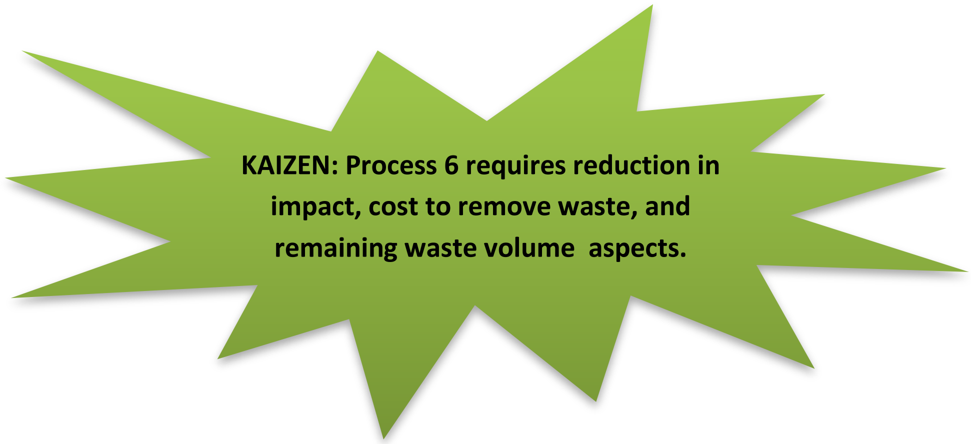


Figure 45: Key output - environmental Kaizen created in response to high impact process and waste identification (Process 6 – Plating: Apply anodize coating).

Once the identification of the 'high impact' processes (shown as red) on the overall system are described and an appropriate environmental Kaizen is created, the 'yellow' processes or neutral levels can also briefly be explored. This exploration might determine which area will likely become the next high impact process from the follow-up use of the environmental impact index implementation. There are four results which fall within the 'yellow' zone or neutral impact. These are processes three, four, five and seven shown in Figure 43 and Appendix E.

8.4 Opportunities from use of the environmental impact index tool

8.4.1 Original environmental value stream map analysis scaling

Identification of the various environmental impacts during index use can provide significant contributions to the entire process analysis. Examining the processes that are marked neutral (or 'yellow') provides insight into further ways to reduce the impact or be aware of impending impacts. A review of processes 3, 4, 5 and 7 provide examples of these insights.

For process 3 (marked 'yellow') on Figure 43, the overall system radar chart illustrates that it is approximately 56% below the maximum target. This would likely mean that process three would not be a high level environmental impact process even within the next iteration of the continuous improvement EII analysis tool. Drilling down to the process level radar chart the results show that process three contributes to nearly 80% of the removed waste (not recycled waste) from the system (Table 14, Process 3, Appendix G).

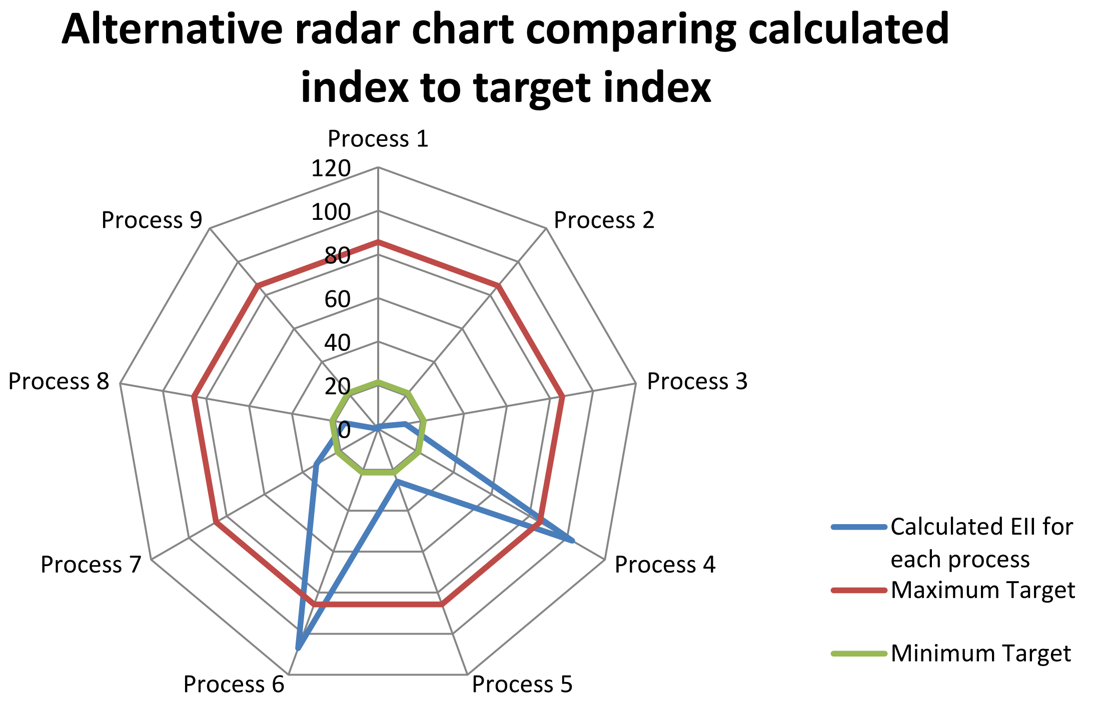
Even though process three is unlikely to become a high system impact process, this analysis shows there is still an opportunity to reduce the total system's environmental impact by reducing this processes individual impact in terms of removed waste. Thus, a Kaizen could be raised for this process due to the high gain that could be achieved and overall system environmental impact reduction through relatively simple actions. For example, one possible solution could be to investigate recycling or reuse of materials at this process step and thus decreasing the environmental impact and increasing total performance.

Another neutral (marked 'yellow') process is number four which is 34% below the maximum target, shown by the summary data in Figure 43. Thus, this process has a higher impact than process three and consequently has a higher likelihood of requiring a Kaizen initiative in the next environmental impact index analysis. A review of the process four radar chart shows that the highest contributing environmental impact factor (EIF) is the cost to remove waste (Figure 55 Appendix E) . This is found to be approximately 50% of the entire system (Process 4, Table 14, Appendix G). This result represents another opportunity for overall system performance and improvement. The next neutral process (marked 'yellow') is process five which is found to just 7% below the maximum EII target (Figure 43). Thus, this process has the potential to be a high EII process in the next iterative implementation due to its large remaining waste contribution of 26%, to the overall system remaining waste (This is indicated by Process 5, Table 14, Appendix G).

Finally, process seven (the last neutral process marked 'yellow' in Figure 43) is shown to be 70% below the maximum target (Shown by the summary data table in Figure 43), even though this process contributes nearly 60% of the system's total carbon footprint (Process 7, Table 14, Appendix G). This is just under 25% of the total perceived impact of the system (Process 7, Table 14, Appendix G). This result differs due to the lack of scaling factor used in this particular implementation.

8.4.2 Alterntive environmental value stream map analysis scaling

Due to the large numerical values of remaining and removed waste multiplied by the risk register value; these automatically become bigger contributors to the final environmental impact index. However, if these were reduced by a factor of 1000, the carbon footprint and cost factors would drive up or down final environmental impact index. This is shown in Figure 46. In this illustration, a scaling factor of 1/1000 has been applied to the remaining and removed waste environmental impact factors (EIFs) shown by Table 18, Appendix H. Figure 46 shows the re-evaluated and corresponding environmental impact index results, whilst simultaneous highlighting several interesting features of the EII analysis methodology.



Process Number	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7	Process 8	Process 9
Calculated Environmental Impact Index (EII)	1	1	13	103	26	107	33	16	0
Max bounded target	86	86	86	86	86	86	86	86	86
Min bounded target	21	21	21	21	21	21	21	21	21
Percent below or above max target	-98.8%	-98.3%	-85.2%	20.0%	-69.9%	25.0%	-61.9%	-81.8%	-99.9%

Figure 46: Alternatively scaled system performance with increase in relative importance of carbon footprint and costs to remove waste with new corresponding environmental impact index results

With the large decrease in weighting for waste volumes (both removed and residual), the calculated index automatically highlights and targets the next large contributors to the final EII. This is exemplified by the change in key high impacts. By comparing Figure 43 and Figure 46, the change is immediately apparent relative to the environmental impact index results. The first change noticed is the decrease in size of the indexes unit value. This is primarily due to the magnitude calculation to determine the final EII for each process which is based off a multiplication of the environmental impact factors (EIFs) by the scaling factor. This therefore changes the appearance of the final system radar chart depending on the initial boundary conditions. On the other hand, the scaling factor does not affect the secondary process level radar charts. This is because the secondary radar charts used to eventually determine the value stream's environmental Kaizen are based on a percentage of EIFs as a component of the total and are percentage based comparisons.

Several different features are highlighted in the scaled value stream. The first major difference is the emphasis of high impact process four, as well as the high impact of process six, as seen in Figure 46. Previously process four was only a neutral level process but due to the change in scaling factor, the high cost of waste removal is now highlighted through the alternative scaling. This is seen in the summary level radar chart (Figure 46) resulting in an impact of 20% over the maximum value stream target. Process five remains a neutral (level) yellow process due to its still very high residual waste volume. This illustrates the exceedingly high impact this process has on the system, even with a scaling factor applied to the environmental impact factor contributor, e.g. the remaining waste volume of this process.

Process six (in the scaled value stream) remains red showing high impact due to:

- its large contribution of cost to remove waste
- its perceived impact
- its still very large remaining waste volume and risk register amount.

Process six still leads the system in terms of impact at 25% over the maximum target EII Figure 46. This further emphasises the enormous impact this process has on the rest of the value stream, dominating most of the index results and even with a scaled waste volume factor. Process seven also remains a neutral impact process at just under 30% below the maximum target EII Figure 46. This is due to the very high carbon footprint contribution, as well as high perceived impact of waste EIF.

Another feature noticeable when comparing both analyses (Figure 43 and Figure 46) is the increase in high impact processes along with an increase in low (green) processes. This is achieved through the ‘reduction’ of yellow processes. While this is not through specific EIF reduction activities but rather due to the desensitisation of the analysis to the environmental impact factor of waste volumes. (The greater the volume, the greater the impact; and the smaller the volume, the smaller the impact.)

The final, and arguably most important, implication of the alternatively scaled system in comparison to the originally scaled system is the secondary environmental Kaizen relating to the second high impact process e.g. process four. The secondary environmental Kaizen for process four is shown by Figure 47. This Kaizen highlights the alternative need to reduce the cost of waste removal. This supplementary Kaizen is in addition to the original environmental Kaizen shown in Figure 45, which stressed the need to reduce cost, to remove waste, perceived impact and residual waste volume.

Figure 47: Key output - environmental Kaizen created in response to the high impact process and waste identification (process 4 – Plating: remove anodize coating) using alternatively scaled system.

8.5 General feedback on implementation

This section will review several key practitioner-based observations made throughout the implementation, along with the significant implications obtained from the sponsor company based questionnaire.

One anecdotal initial reaction to the index implementation provides key insight to the future use of this process and system. One practitioner was asking another for the reasoning behind the project. Before an answer was given, a third practitioner was able to identify, reason out and explain that the method would allow the user or company to help set up and evaluate Environmental, Health and Safety goals, as well as allowing the user to determine the process level environmental impact and attribute overall data waste to a specific source within the system. This acknowledgement is considered a critical point in the development of the index, since the primary purpose of the project was to enable a vertical integration of high level data with process level environmental impacts. And further this exchange demonstrates that participants will have the desire, as well as the knowledge to use this information so that it can be integrated with the company's continuous improvement processes including kaizen creation.

A surprising result was the increase in practitioner knowledge with the use of the index. The index effectively shows the environmental impacts, but it also increases the overall practitioner knowledge about the environmental impacts and performance, as well as gaining knowledge about the environment as a whole. One practitioner was able to summarise this point by describing "the journey of determining the environmental impacts was just as important, or perhaps even more so then the end result of creating the index". In the words of another practitioner at the implementation event, "[The method] helps show what's happening for each process at an environmental level, not just at a time or cost level". This observation shows the increased sensitisation of staff towards the overall concept of environmental waste in the lean production setting. This sensitisation also represents an opportunity to align staff and practitioners to environmental and strategic goals, such as waste impact reduction, and environmental considerations. Not only does the tool have direct functional benefits for production by capturing and quantifying environmental waste data, there is an additional competitive advantage in increasing awareness companywide of environmental performance which is a metric to be measured and improved. This reinforces the concept that the method is not just a simple calculation tool but a wider environmental impact assessment methodology.

In reviewing the process, once the theory was examined, explained and understood, implementation commenced. During the implementation stage, one adjustment was made when difficulties arose when trying to capture required EIF data. Due to the relatively high amount of data required for each process (considering five environmental factors for each), the capture process was relatively slow and often assumptions had to be made along with estimations of data. The estimation of data was kept to a minimum by ensuring that experienced practitioners could 'walk the line' to determine what information was required or missing. The use of optimistic, pessimistic and expected values for EIF was found to speed up the data capture process if an exact value was not forthcoming.

One of the key aspects that will be mentioned further in Section 8.7 is the carbon footprint calculations. These calculations were found to be difficult to develop; requiring sets of hand calculations and data estimations to determine the carbon footprint equivalences. This included carbon footprint equivalence for every process involved including lights, electricity use, heaters and computers to transportation and so forth. One of the most noted continuous improvement feedback points was the inclusion of an automatic carbon footprint calculator that would immensely improve the performance and usability of the EII tool.

8.6 Conducting a survey

To further validate the effectiveness of the created EVSM method and associated index, a survey was conducted at the CEC. The focus of the survey was the implementation of the environmental impact assessment tool on the Annulus filler process as described in section 8.2. The University of Canterbury approved survey questions (found in Appendix D) are summarized as follows:

- Question 1: To what extent is it important to measure environmental waste impacts?
- Question 2: What was the number of times the practitioner used the tool?
- Question 3: To what extent does the practitioner feel the tool was successful in promoting new thinking and continuous improvement?
- Question 4: To what extent does the practitioner feel method was effective at identifying environmental waste impacts?
- Question 5: What environmental impact factor (EIF) was most appropriate?
- Question 6: What environmental impact factor (EIF) was least appropriate?
- Question 7 (optional): What did the practitioner find difficult (or one thing they would change)

The results from questions one three and four are illustrated in Figure 48.

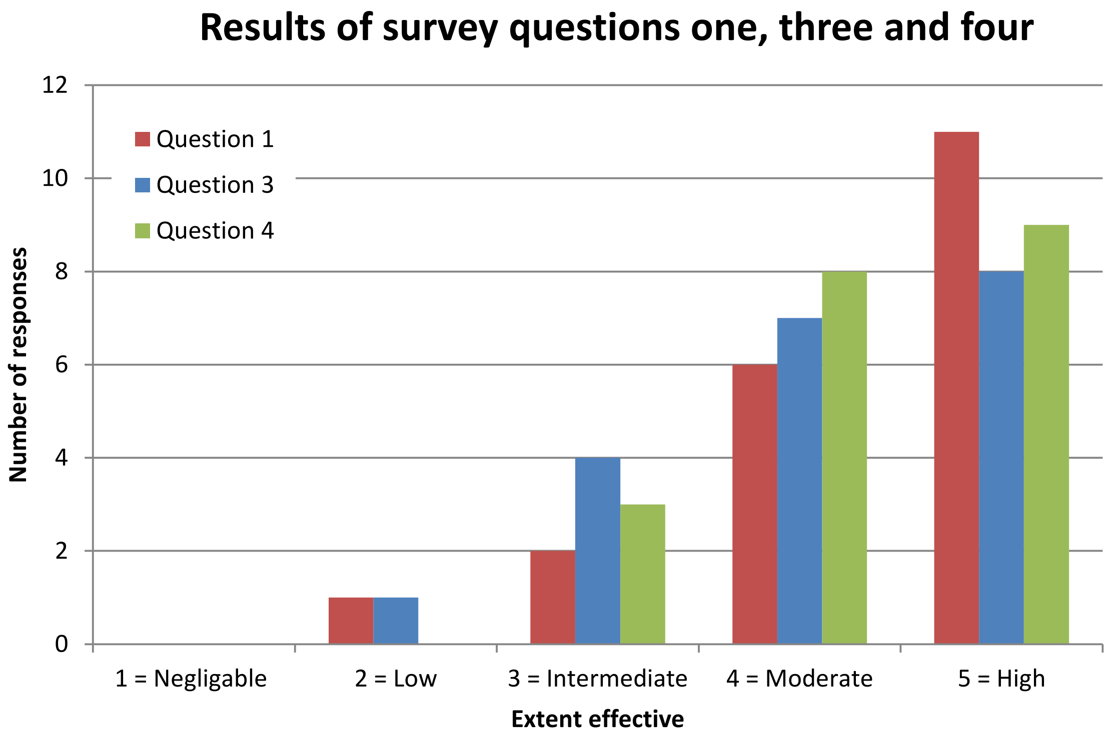


Figure 48: Results of survey questions one, three and four: validating method and results through practitioner based questionnaire These results demonstrate effectiveness of the method.

The results from survey questions five and six are summarised and described in Section 8.7 along with the question seven comments and corresponding actions.

Question one

That first correlation that can be inferred from the question one results also relate to the change management model. This question indicated the extent that the index was successful in promoting *communication* of core business values; primarily the importance of environmental waste impacts. (Communication was one of the pillars in the created change management model.) Question one data showed a high appreciation of the practitioners surveyed in understanding process level waste impacts. The data showed over 35% of the practitioners felt it was moderately important to measure environmental waste impacts; with 55% of staff feeling it was highly important. The communication of this key business value was a crucial element in the development and deployment of the all methodologies developed during this project. It was felt this was achieved through clear, precise communication of the research purpose and goals. The use of clear communication reinforced or created an awareness, so that 85% of practitioners appreciated the need to understand and measure environmental waste impact.

Question two:

Question two data was to be used to create a practitioner learning curve comparison analysis, but due to a site wide consolidation within CEC at the end of the project and further unforeseen circumstances a secondary implementation could not be achieved.

Question three:

Question three relates to the openness of the practitioner to continuous improvement initiatives. This also relates the use of *culture* as a change management tool. (Culture was another pillar in the change management model.) The data showed 35% of practitioners felt the tool was moderately successful in promoting new thinking and continuous improvement, whilst 40% felt the tool was highly effective at promoting new thinking. This suggests that while there is an embedded culture at the CEC, it allowed the environmental impact index tool and overall methodology to be successfully integrated into the pre-existing lean continuous improvement initiatives.

Question four:

Question four directly relates to the effectiveness of the environmental impact index and the methodology to identify waste which allowed for the creation of environmental Kaizen initiatives. The data showed the method was exceptionally effective at identifying high environmental waste impact processes. This is supported by the fact that over 85% of practitioners felt the method was moderately to highly effective at identifying environmental waste impacts, resulting in the creation of environmental Kaizens. The breakdown of question 4 results showed no respondent believed the method had a negligible or low ability to identify environmental impacts. Fifteen percent believed the method was intermediately effective, 45% moderately effective and finally 40% highly effective at environmental identification which was the original purpose outlined for the thesis.

8.7 Modification of method and index for future-proofing

With all engineering systems and tools, there are always opportunities for future improvements and modifications to improve the system's performance. As mentioned previously, one of the first modifications and improvements made during the implementation process was the inclusion of a carbon footprint calculator to ensure easier capture of the carbon data points. The calculator was included in the excel tool as a separate excel page (shown in Appendix and

Table 15) which determines the carbon footprint equivalence of (for example):

- lights used per bulb per hour
- computer use per person
- heating of plating tanks per tank and per hour

Basic energy unit conversions and general electrical equipment conversions were also embedded.

After the implementation was completed, the survey (Section 8.6) was used to determine effectiveness of the factors which were used for this particular implementation and areas of improvement for the overall method and index aggregation. Further modifications of the method were suggested as a result of the fifth and sixth survey questions. These two questions attempted to determine which EIFs were the most and least appropriate factors, as shown in Figure 49.

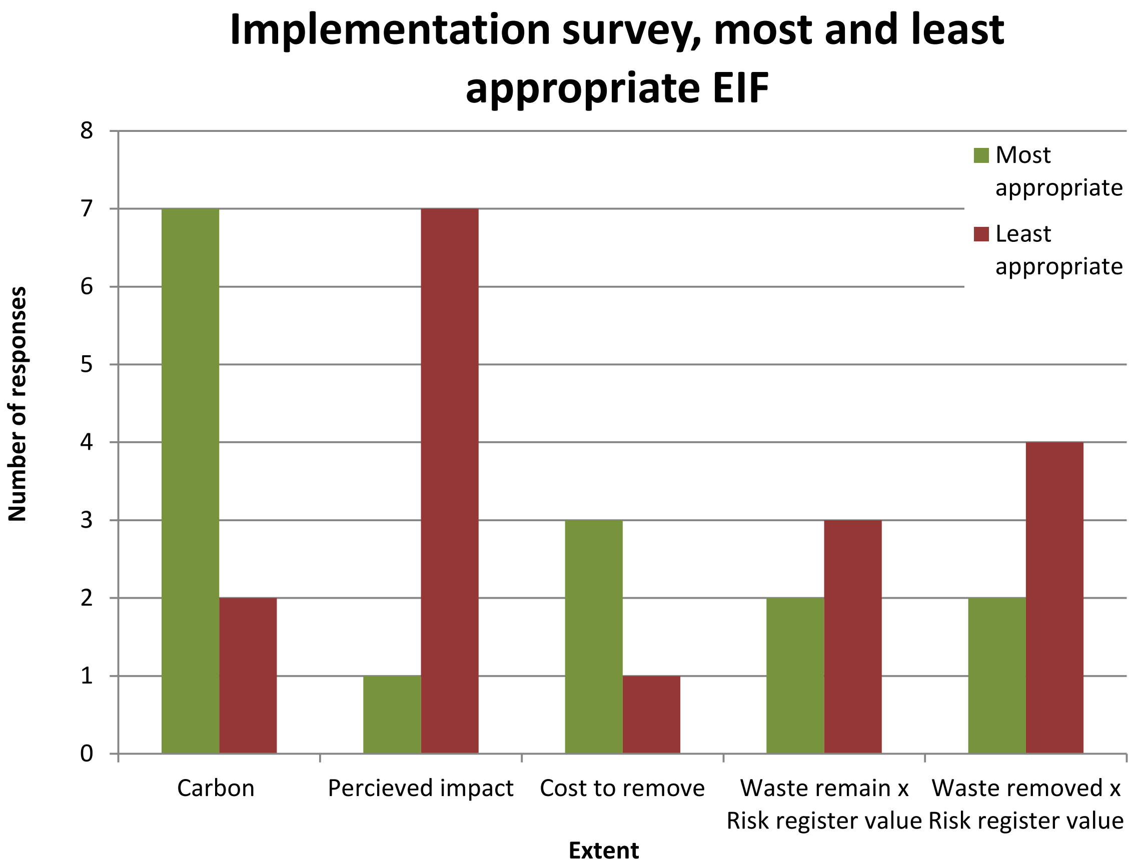


Figure 49: Most and least appropriate environmental impact factors from practitioner-based questionnaire data.

The data suggests a strong correlation of approval for the carbon footprint factor with 40% of practitioners suggesting it was the most relevant and important factor and only 5% practitioners feeling it was the least appropriate factor. This suggests carbon footprinting should remain as a key metric in any future modification to the index. Figure 49 also shows the fact entitled 'impact' was the least appropriate aspect with only 10% approving of it and 35% feeling it was the least suitable of all the EIFs. It is noted that 'cost to remove' had more positive votes than negative and thus was more fit as an impact factor. As an appropriate EIF, there were 15% for and 10% against. However people found the waste removed impact factor slightly less appropriate then waste remaining.

Finally, waste removed was seemingly not appropriate for use as a factor. It is recommended that further studies be done on what factors might seem the best for evaluation. It is possible that a broader survey with more options and larger survey results may yield more conclusive outcomes.

The final question in the validation survey was intended to determine key areas for improvement, by asking: "what was found difficult or what was one aspect the practitioner would change with respect to the methodology or index". Some of the responses from the practitioners are described in Table 10, along with the corresponding actions undertaken to resolve the issue. This particular question also relates to the third pillar of the change management model which is 'commitment'. Question seven in the survey was designed to examine the self-efficacy of the practitioners involved during and after the implementation, as well as the practitioner's motivation. A review of the comments demonstrated a high commitment from staff due to the high level of responses and constructive feedback of the staff in an effort to continuously improve the project.

Table 10: Post implementation survey results with selected practitioner comments and remediation actions suggested for method and index

Practitioner comment	Action to improve method as a result of practitioner comments
"Method should include automatic calculators for carbon footprint and standard processes" (Multiple comments with regards to this aspect.)	Carbon footprint calculator has been created as an extra sheet in the excel spreadsheet which now determines the carbon equivalence using set power inputs.
"Be careful of language – try to phrase things to suit CHCEC terminology and reduce unfamiliar words"	Communication of standard operating procedures has been reviewed and edited. Abbreviated words were expanded, phrases explained and details reduced or removed where possible.
"Finding tool"	Possible confusion in terms of availability of tool, due to fact that tool has not been released site wide yet.
"Would add just a separate waste removed volume factor, and separate risk register value and agglomerate after"	This was considered at the start of the composite index creation but due to organisational constraints, the EIF values at this point will remain the same. Defining future modifications in terms of a specifically defining a new set of EIF

	are out of scope for this project. Changes in EIF values would most probably be decided through further focus group reviews with heads of the primary business groups.
"May be worth having the ability to set key factors to the type of tasks being reviewed prior to performing review. VSM can cover any type of process (Business vs. operational)"	This was resolved by allowing the agglomerated index to reflect any number of chosen EIFs and allowing any production process or information system (Business vs. operational) system to be analysed depending on the initially defined and the chosen EIF.
"From P2 perspective, all factors are appropriate to track and understand. Well done. Don't know if I would change anything!"	No action required.
"Legend for new abbreviations"	A legend was created summarizing all abbreviations for quick reference by the user/ practitioner.
"Are we not trying to eliminate waste, so would this not make the perceived impact of waste only required for the calculation and not needed to be shown on the radar, therefore we should only focus on waste reduction which is shown by the minimum target"	This can be achieved by only plotting what factors are required for a particular analysis. The minimum and maximum targets were set to provide a realistic boundary to which the practitioner or user could aim. But these can be set to the same amount to provide an indication for the long term, future goals or aspirations of a particular company.

8.8 Summary

The environmental impact index (EII) methodology was successfully implemented and integrated into Value Stream Mapping at the CEC. The trial suggested an excellent correlation to the expected result of integrating environmental impacts (both positive and negative) into VSM. The methodology helped to focus waste elimination through the use of Kaizen, not just from a cost saving perspective but also to promote a green thinking. The implementation results and questionnaire data validated the methodology created. The initial research premise was validated with a clear ability to integrate organisational data for production level processes, allowing an environmental Kaizen to easily be created. The original purpose of the thesis was fulfilled through the application of a customisable environmental impact index methodology. This was integrated with VSM use and allowed for effortless identification of environmental Kaizen(s) for high environmental impact processes.

9 Discussion: implications and contributions

This chapter will focus on the overall implications and contributions of the work submitted. The chapter will discuss the primary consequences for the practitioner and the successful aspects of both the visual presentation and the environmental impact index calculations. The chapter will also examine the contributions to the body of knowledge made, limitations of the work conducted, possible future work and finally a summary of the project results.

9.1 Discussion and implications for practitioners

The original purpose of this project was to design and develop a method in which the environmental characteristics relative to a set of industrial production engineering processes could be measured, analyzed and improved. This included integration of this method with a typical Value Stream Mapping operational procedures. As a result of this project, a comprehensive environmental impact analysis methodology has been created and integrated into VSM use. This included implementation within an industrial setting—the Christchurch Engine Centre of Pratt and Whitney. The design and implementation of the created method fulfils the original design specifications of providing a framework measuring the time domain (Value Added and Non-Value Added), as well as allowing the environmental impact domain to be successful mapped through the use of a modified VSM process.

Industry practitioners at the production level now have a method to identify specific improvement activities (e.g. Kaizen) for environmental waste, consistent with the organisational priorities and as required by the original brief. Thus, environmental waste can be considered alongside other forms of waste during the VSM process as seen in Figure 50. To implement this, production engineers and supervisors would thus apply the environmental waste considerations as part of VSM (see action 2.2 in Figure 50), and then develop Kaizen in the normal manner. Optionally, they can also report back to senior management against objectives for environmental waste.   They can do this at the level of a whole value stream or individual processes.

Complementary to that, senior management now have a method to take the external environmental standard ISO14001 and develop a customised construct for environmental waste for their particular organisation. They can then align the production processes (particularly the priorities going into the continuous improvement processes) to achieve those organisational objectives. Thus, the method provides a strategic tool for firms that seek to improve their environmental position, as reflected in the improvement process in Figure 50. A further implication from a management perspective is that the method has been developed with implementation and change management in mind.

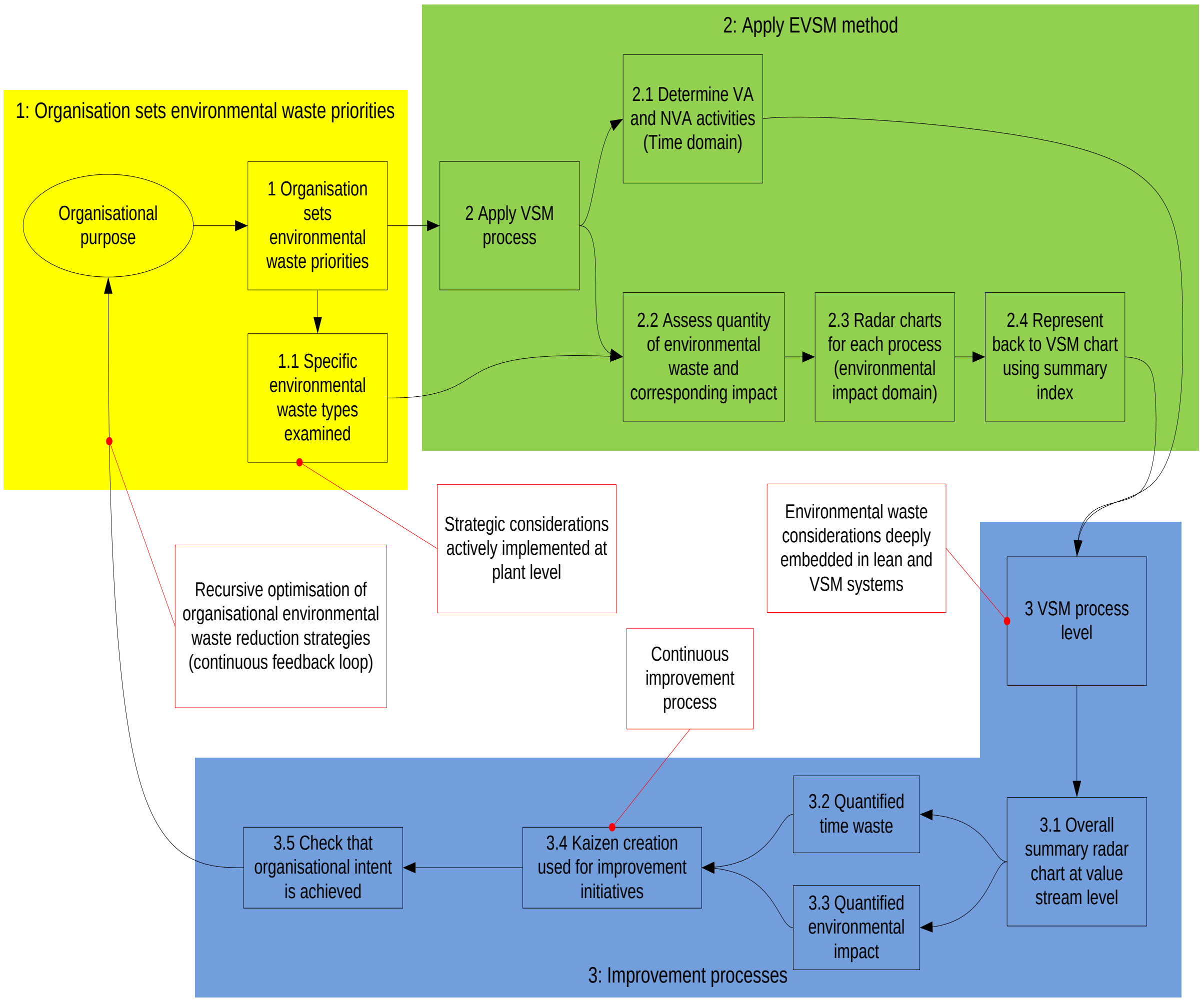


Figure 50: Summary of the overall method as implemented in industry. (T. Roosen illustration)

The entire system has been specifically designed to be easy to implement and to fit in with the existing organisational culture. It achieves this by being complementary to the established practices of lean and VSM in particular. It also takes advantage of practices and ideas with which the organisation is already familiar. To implement this method, executives and production managers would decide on *which* environmental wastes to include and *set* the priorities for each (See action 1 in Figure 50). Production staff would then implement this alongside the usual VSM processes. One of the quality staff would need training to use the method for consistency and overall monitoring, but widespread training of other staff is not necessary (providing they already know how to implement VSM). Executives can then request summary information on the overall environmental waste burden and efficacy of improvement measures. They can then use this information to further refine the strategic approach to manage the environmental waste. The results showed that the modified EVSM method successfully portrayed system environmental impacts. An extended value stream was examined revealing high and low environmental impact processes. The practitioner was able to effectively and efficiently determine the highest impact processes, as well as pinpoint the source of the environmental waste with respect to the initial examination criteria.

The effectiveness of the methodology is reflected by both the ease at which environmental Kaizen were determined, as well as by the positive questionnaire data received through the practitioner feedback.

The most effective visual characteristic was the use of multi-tier radar diagrams to reflect the resulting information. The overall system summary radar chart successfully showed what process required targeting, whilst the second tier radar chart (focusing on the environmental impact factors) quickly summarised what part of that process required Kaizen creation. This multi-tiered visual representation was successful in ensuring the large amount of information gathered could be interpreted quickly, as well as allowing for quick comparisons of multiple processes across the system. The use of visual upper and lower target bounds was also very successful at helping to identify maxima and minimum environmental impacts calculated, which further defined the high profile environmental impacts.

A new initiative was that the method uses the Pareto concepts in a world-first application. The threshold bounds were useful in determining a Pareto-type ranking of processes with respect to their impact. This allowed practitioners to identify a possible second iteration process that would likely result in high environmental impacts. The process summary environmental value stream bar (which allowed for quick impact assessment) was also successful in showing non-practitioners the areas within the plant and production line that corresponded to high and low environmental impacts.

Several aspects of the calculation component of the environmental impact index worked very well in determining a final overall impact. The magnitude vector approach was very successful in accumulating the various components of the evaluation criteria into a singular value. The scaling factor was shown to be effective in highlighting different waste criteria. It assisted in relating to the key criteria for success and ensuring that the changing organisational purpose of a company could be reflected by the changing focus of its environmental impact factors.

An important component that was altered to improve the usability of the method was to recalculate upper and lower thresholds boundaries by a total percent instead of requiring the practitioner to estimate the upper and lower thresholds. This was far more effective at determining an upper and lower threshold and reduced the input requirements for the practitioner. The estimation of data for each process was improved through the use of a beta distribution calculation. Finally, the addition of a customised carbon footprint calculator further reduced the input requirements for the practitioner and simplified the data acquisition process.

9.2 Contributions to body of knowledge made through development of this index

This work has made several contributions to the body of knowledge regarding environmental Value Stream Mapping and lean manufacturing principles. The first contribution is the creation of a method to integrate environmental impacts and lean methods. Specifically, the index has reflected integration from:

- the generic *environmental standard* ISO14001
- through to the *organizational environmental risk register*
- onwards to integration within the *VSM process*
- and thus finally permitting the established lean *improvement process* (e.g. kaizen) to be focused at specific environmental improvement actions.

Thus, the index development takes the abstract concepts of environmental waste and makes them practical to identify and thus able to eliminate or reduce. Specifically, this project has developed a method to incorporate environmental waste within the VSM lean method. The complete overview of this methodology is shown in Figure 50.

A second contribution is the development of an n^{th} dimension environmental factor methodology to create a *customised* environmental waste index for a particular industry. While the index created for this specific case used carbon footprint, perceived impact, cost to remediate, and waste volumes (removed and residual), the method is capable of being altered to use different factors, as well as any number of factors.

A third advancement is that a creative way was developed to use *ambiguous user estimates* of the quantity of each type of waste. This provides a basis for estimating values that are imprecise and otherwise difficult for operators to commit a single deterministic value. Thus, the method is capable of identifying areas for improvement (which is the overall purpose), despite ambiguous and imperfect information. To achieve this, the PERT beta distribution was used, which already has established acceptance in the project-management field.

A fourth contribution is the design of a method to represent the multi-dimensional environmental wastes that are relevant to diverse industry situations. Specifically radar charts were used to help display process level environmental impacts to overall system data, as well as attribute environmental impacts to the source of the problem. This concept also allows the practitioner to drill down or up from a process to an overall system level (or vice versa) for the required information.

The contributions are summarised as:

- Created a condensed practitioner focused change management model and used the model to help implement the environmental impact index methodology.
- Analysed current VSM use at CEC and provided critical review of operational procedures to improve VSM implementation and performance.

- Formed an appropriate methodology for the creation of an environmental impact index and encased the methodology in a user friendly form (as required by the sponsor) for use at CEC as a supplementary environmental VSM analysis tool
- Created an effective change management model to be used when implementing the new engineering principles for industry-based improvements. The model was centred on the concepts of effective communication, commitment and culture of the practitioner.
- Defined a set standard operational procedures (SOP) to ensure clear and effective communication of environmental impact index methodology use to the industry practitioners through use of the created change management model.
- Tested the environmental impact analysis methodology on VSMs at the CEC, allowing a concise list of appropriate environmental Kaizen events to be created. This allowed summary environmental waste data to be effectively integrated with the tools of quality and process improvement which primarily focused on VSM use.
- Analysed the effectiveness (and efficacy) of the environmental impact method to determine that the method effectively produced key Kaizen initiatives for resolution. This proved the model was able to integrate environmental impacts (both positive and negative) into the VSMs to focus on waste elimination from the Kaizen perspective, not just from the cost saving perception. This further promoted greener or safer manufacturing and engineering processes and practices.
- Analysed effectiveness of developed change management model used with the implementation of the environmental impact index tool. Analysis showed effective use of all three key change management aspects to ensure a successful index implementation. This was verified through the use of a quantitative survey.
- Future proofing of the environmental impact index occurred through recommending areas of improvement of the methodology and environmental impact index model.

9.3 Limitations and opportunities for further research

One limitation initially noted is that while the index integrated *environmental waste* with *lean manufacturing* practices, the integration was only developed for Value Stream Mapping (VSM). There are many other lean methods and not all organisations use VSM. Where ‘time’ is the main driver of cost or quality, then VSM is appropriate, but this is not relevant to the production economics of all organisations. Furthermore, the integration has only been demonstrated for the manufacturing industry. There are many other industries that use lean principles, such as service organisations and project management, and the method has not yet been tested there. Consequently, there are opportunities for future research to extend, adapt and improve the method created. Initial future proofing on the created method was initiated at the end of the first implementation with questionnaire data gathered as to what the practitioners would modify or improve. This was summarised in Table 10 in Chapter 8.

Another opportunity for future improvements is the initiation of further implementations of the method in new scenarios and larger value streams. This would allow improvements, such as the created carbon footprint calculator which was included and adapted so that the method would be more robust and could be applied to a greater set of scenarios. The continuation of iterative testing and implementation would allow further refinement, not only to the methodology but also to the index and visual representation aspects as well.

Another feature that could be adapted would be the re-examination of the chosen environmental impact factors. This would be primarily to ensure that the environmental impact factors reflected the changing goals and organisational purpose of the company where the method is being applied. The re-evaluation of the environmental impact factors could also allow the practitioner to separate out aspects that could be examined independently, such as the inclusion of a separate toxicity scale. There is also the possibility that an organisation would want the combined components of remaining and removed waste with risk register values to be separated out into their constituent components and to further refine the analysis. Once the system has been tested in various environments, a logical adaption would be to create a Graphical User Interface (GUI) and embed the method in a program that would automatically fill the data acquisition boxes, as well as automatically create the embedded environmental value stream ladder. This would further reduce required inputs from the practitioner, as well as speed up the index creation. The proposed program could also include both the carbon footprint calculator, as well as automatically compile and create the process radar charts including the summary system radar charts. At this stage, the method already updates the radar charts and the calculated values if alterative data is entered, but it does not create new radar charts if an increased number of processes are added.

10 Conclusions

The original purpose of this work was to include the aspect of environmental waste into lean thinking and practices. Specifically, it is important in ensuring that environmental waste considerations are embedded in the production activities to allow for continuous improvement or Kaizen initiatives to take place on the environmental waste aspects. Without this synergy, the deployment of sustainability measures through the production system is hindered. This includes from the management perspective down to the level of individual processes and operator work teams. Also, from the more general environmental perspective, identification and specification of the type of waste is important because of the different toxicities and effects on the environment. There is a lack of vertical integration between the organisational data on environmental waste and the specific industrial processes that originally created the waste (i.e. the source of the waste).

This work developed a method to integrate environmental and lean methods. The method has been developed and tested in a manufacturing setting and is able to represent a variety of environmental wastes within the value stream mapping (VSM) method. Specifically, the index has reflected integration from:

- the generic *environmental standard* ISO14001
- through to the *organizational environmental risk register*
- onwards to integration within the *VSM process*
- and thus finally permitting the established lean *improvement process* (e.g. kaizen) to be focused at specific environmental improvement actions

For the intial testing, the deployment used the factors of carbon footprint, perceived impact, cost to remediate and waste volumes (removed and residual). However, the method is capable of being generalised to n^{th} dimension environmental factors. It is thereby able to represent a *customised* environmental waste index as desired by a particular industry. A*mbiguous user estimates* of waste quantities are accommodated through the PERT beta distribution. Several ways to represent the multi-dimensional environmental wastes were explored via industry focus groups and the preferred representation was designed to completion. The resulting method can be used by production staff and represents environmental impacts at the level of the individual process work and included with the whole value stream for that process. The method may also be used by executives to align organisational practices with strategic objectives for waste reduction and environmental Kaizen initiatives.

References

Abdulmalek, F. A. and J. Rajgopal (2007). "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study." International Journal of Production Economics **107**: 223-236.

Balogun, J. and M. Jenkins (2003). "Re-conceiving Change Management:: A Knowledge-based Perspective." European Management Journal **21**(2): 247-257.

Biloslavo, R. and A. Trnavcevic (2009). The factors of choice of change methods: what is their impact on consequences of change? PICMET '09 - 2009 Portland International Conference on Management of Engineering & Technology, 2-6 Aug. 2009, Piscataway, NJ, USA, IEEE.

Bontoux, L. and F. Leone (1997). The Legal Definition of Waste and its Impact on Waste Management ind Europe. E. C. (EU). Spain, Institute for Prospective Technological Studies. **European Directive 75/442/EC as amended**.

Braglia, M., G. Carmignani, et al. (2006). A new value stream mapping approach for complex production systems, Taylor and Francis Ltd.

Braungart, M., W. McDonough, et al. (2007). "Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design." Journal of Cleaner Production **15**(13–14): 1337-1348.

Brinkley, A., M. Karlsson, et al. (2000). Systematic environmental assessment: a decision methodology for strategic environmental issues. Electronics and the Environment, 2000. ISEE 2000. Proceedings of the 2000 IEEE International Symposium on.

Cabrera, Á., E. F., et al. (2001). "The key role of organizational culture in a multi-system view of technology-driven change." International Journal of Information Management **21**(3): 245-261.

Carnall, C. A. (1995). Managing Change in Organisations, Prentice Hall, London.

Chen, J. C., L. Ye, et al. (2010). "From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study." International Journal of Production Research **48**: 1069-1086.

Chu, K. F. (2003). "An organizational culture and the empowerment for change in SMEs in the Hong Kong manufacturing industry." Journal of Materials Processing Technology **139**(1–3): 505-509.

David, P. (1996). "The project management of organizational change." International Journal of Project Management **14**(1): 13-21.

Deming, W. E. (1986). Out of the crisis. Cambridge, MIT Press.

Diefenbach, T. (2007). "The managerialistic ideology of organisational change management." Journal of Organisational Change Management **20**(1): 126-144.

Dyck, B. and F. A. Starke (1999). "The formation of breakaway organizations: Observations and a process model." Administrative Science Quarterly **44: 792**.

EPA (2000). Pursuing Perfection: Case studies examining lean manufacturing strategies. U. S. Environmental Protection Agency. Washington D.C.

EPA (2003). Lean Manufacture and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recomendations for Leveraging better Environmental Performance. U. S. Environmental Protection Agency. Washington D.C.

EPA. (2011). "EPA, The lean and Environmental Toolkit." Retrieved 22/08/2011.

Grebe J.C, Jr. (2001). Effective engineering management in the next decade. Change Management and the New Industrial Revolution (IEMC'01), October 7, 2001 - October 9, 2001, Albany, NY, United states, Institute of Electrical and Electronics Engineers Inc.

GRI (2006). G3 Stustainability Reporting Guidelines. Amsterdam, Global Reporting Initiative.

Gurumurthy, A. and R. Kodali (2011). "Design of lean manufacturing systems using value stream mapping with simulation A case study." Journal of Manufacturing Technology Management **22**(4): 444-473.

Hart, S. and G. Ahuja (1995). "A Natural Resourced Based View of the Firm." Academy of Management Review **20**(4): 985-1014.

Hicks, B. J. (2007). "Lean information management: understanding and eliminating waste." International Journal of Information Management **27**: 233-249.

Hines, P., M. Holwe, et al. (2004). "Learning to evolve: a review of contemporary lean thinking." International Journal of Operations & Production Management **24**: 994-1011.

Hines, P. and N. Rich (1997). "The seven value stream mapping tools." International Journal of Operations & Production Management **17**: 46-46.

Hokerby, I. (1993). "Environmentally Compatible Product and Process Development." NAE Workshop on Corporate Environmental Stewardship.

Irani, S. (2004). Value Network Mapping (VNM): Visualization and analysis of multiple interacting value streams in jobshops. 4th Annual Lean Management Solutions Conference 2004, Sep 12 - 16 2004, Los Angeles, CA, United states, Institute of Industrial Engineers.

ISO:14031 (2000). Environmental Managment - Environmental Performance Evalutation Guidelines, ISO 14031:2000. Geneva: International Organization for Standards.

ISO:14040 (2006). Environmental management - Life cycle assesment - Principles and framework; ISO 14040:2006. Geneva: International Organization for Standards.

Jasch, C. (2003). "The use of Environmental Management Accounting (EMA) for identifying environmental costs." Journal of Cleaner Production **11**(6): 667-676.

Karlsson, C. and P. Ahlstrom (1996). "Assessing changes towards lean production." International Journal of Operations & Production Management **16**(2): 24-41.

Kezar, A. J. (2001). "Understanding and Facilitating Organisational Change in the 21rst Century." ASHE-ERIC Higher Education Report **Volume 28 Number 4**.

King, A. A. and M. J. Lenox (2001). "Lean and green? An empirical examination of the relationship between lean production and environmental performance." Production and Operations Management **10**: 244-256.

Kotter, J. P. (2009). "Leading change: Why transformation efforts fail." IEEE Engineering Management Review **37**(3): 42-48.

Kotter, P. J. (2007). "Leading change - why transformation efforts fail." Harvard Business Review **85**(1): 96-103.

Kuhlang, P., T. Edtmayr, et al. (2011). "Methodical approach to increase productivity and reduce lead time in assembly and production-logistic processes."

Kurstedt Jr, H. A., L. A. Mallak, et al. (1990). Why engineers must know and manage organizational culture. 1990 International Engineering Management Conference, October 21, 1990 - October 24, 1990, Santa Clara, CA, USA, Publ by IEEE.

Lasa, I. S., R. de Castro, et al. (2009). "Extent of the use of Lean concepts proposed for a value stream mapping application." Production Planning and Control **20**: 82-98.

Lian, Y. H. and H. Van Landeghem (2007). "Analysing the effects of Lean manufacturing using a value stream mapping-based simulation generator." International Journal of Production Research **45**: 3037-3058.

McDonough, W. and M. Braungart (2002). Cradle to cradle: Remaking the way we make things, North Point Press.

Melton, T. (2005). "The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries." Chemical Engineering Research and Design **83**(6): 662-673.

Monden, Y. (1993). Toyota Production System: An Integrated Approach to Just-in-Time, Industrial Engineering and Management Press: Norcross, GA.

Morgan, G. (2006). Images of Organisations, Sabe Publications, California.

Navarre, C. and J.-L. Schaan (1987). "International engineering project management: key success factors in a changing industry." International Journal of Project Management **5**(4): 238-245.

Oppenheim, B. W. (2004). "Lean product development flow." Systems Engineering **7**: 352-376.

Patil, A. S. (2002). Incorporating environmetnal index as waste into value stream mapping. Mechanical Eningeering, Masters of Science, Major of Industrical Engineering. Wichita, Wichita State University,**:** 93.

Pohjola, V. J. and E. Pongrácz (2002). "An approach to the formal theory of waste management." Resources, Conservation and Recycling **35**(1–2): 17-29.

Pongrácz, E. and V. J. Pohjola (2004). "Re-defining waste, the concept of ownership and the role of waste management." Resources, Conservation and Recycling **40**(2): 141-153.

Richards, D. (1994). "Environmentally Consious Manufacturing." World Class Design to Manufacture **1**(No 3): 15-22.

Rother, M. and J. Shook, Eds. (1999). Learning to see: value stream mapping to add value and eliminate MUDA, The Lean Enterprise Institue, Brookline, MA.

Salhofer, S., G. Wassermann, et al. (2007). "Strategic environmental assessment as an approach to assess waste management systems. Experiences from an Austrian case study." Environmental Modelling & Software **22**(5): 610-618.

Schein, E. H. (1990). "Organisational Culture." American Psychologist **45**: 109-119.

Serrano, I., C. Ochoa, et al. (2008). "Evaluation of value stream mapping in manufacturing system redesign." International Journal of Production Research **46**: 4409-4430.

Seth, D. and V. Gupta (2005). "Application of value stream mapping for lean operations and cycle time reduction: An Indian case study." Production Planning and Control **16**: 44-59.

Singh, B., S. K. Garg, et al. (2011). "Value stream mapping: Literature review and implications for Indian industry." International Journal of Advanced Manufacturing Technology **53**: 799-809.

Singh, B. and S. K. Sharma (2009). "Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm." Measuring Business Excellence **13**: 58-68.

Tapping, D., T. Luyster, et al. (2002). Value Stream Management, Productivity Press, A Division of Kraus Productivity Organization.

Torres, A. S., Jr. and A. M. Gati (2009). Environmental Value Stream Mapping (EVSM) as sustainability management tool. PICMET '09 - 2009 Portland International Conference on Management of Engineering & Technology, 2-6 Aug. 2009, Piscataway, NJ, USA, IEEE.

Van de Ven, A. H. and M. S. Poole (1995). "Explaining development and change in organisations." Academy of Management Review **20**.

Wiedmann, T. and J. Minx (2008). Chapter 1, A defintion of "Carbon Footprint". In C.C Pertsova, Ecological Economics Reserach Trends. New York, Nova Science Publishers.

Womack, J., D. Jones, et al. (1991). The Machine That Changed the World : The Story of Lean Production, {Harper Perennial}.

Womack, J. P. (2006). "Value stream mapping." Manufacturing Engineering **136**: 145-145.

Womack, J. P. and D. T. Jones (1996). Lean thinking: Banish waste and create wealth in your corporation. London, Simon and Schuster.

Worcester, R. M. (1970). "Managing change." Long Range Planning **3**(1): 31-35.

Appendix A: Glossary of Terms

5 S principles: Sorting, straightening, systematic cleaning, standardizing, and sustaining.

CEC: Christchurch Engine Centre

EAM: Environmental Accounting Methods

ECI: Environmental Condition Indicator

EIF: Environmental Impact Factor

EII: Environmental Impact Index

ELP: Environmentally Lean Production

EMA: Environmental Management Accounting

ENI: Environmental Impact

EPA: Environmental Protection Agency

EPE: Environmental Performance Evaluation

EPI: Environmental Performance Indicator

EVSM: Environmental Value Stream Mapping

First In-First Out (FIFO): A system for keeping track of the order in which information or materials are processed

GHG: Green house gasses

GRI: Global Reporting Index

Heijunka: Production levelling. The general idea is to produce intermediate goods at a constant rate, to allow further processing to be carried out at a constant and predictable rate.

Just In Time (JIT): Also known as the Toyota Production System uses signals or Kanbans between different points in the process to notify production when to make the next part.

Kaizen: Kaizen is a product of the paradigm ‘good is never good enough’ and no process can ever be perfect; so operations seek to improve continuously and strive for innovation and evolution.

Kanbans: Kanbans is not an inventory control system rather it is a scheduling system that tells the producer what to produce, when to produce and how much to produce.

LCIA: Life Cycle Impact Assessment

Life Cycle Assessment (LCA): Compilation and evaluation of inputs and outputs and the environmental

MPI: Management Performance Index

MRO: Maintenance, Repair and Overhaul

OEE: Overall equipment efficiency is the hierarchy of metrics which evaluates and indicates how effectively a manufacturing system is operating.

OPI: Operational Performance Evaluation

P&W: Pratt and Whitney (Christchurch Engine Centre parent company)

Single Minute Dye Exchange (SMDE): SMDE is another of the many Lean Manufacturing methods for reducing waste. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product.

Six-Sigma: Six-Sigma is a quality improvement process that seeks to identify and remove the causes of defects by minimising variability.

Takt (from Taktzeit meaning cycle) time: Takt time is commonly known as cycle time with the units of minutes of work over the unit produced. Takt time is calculated by dividing net available work time by customer demand (units required per day).

TOC-BDR: Theory of Constraints refers to the identification of the 'weakest link' or largest constraint within an organisation and removal of production dependency on that link. Drum Buffer Rope refers to protection of the weakest link in the system against process dependencies.

Value Stream Mapping (VSM): Value Stream Mapping is a Lean Manufacture process in which material and information flows can be mapped and optimised by identifying Non-value Added activities compared to Value Added activities.

Appendix B: Current engines remanufactured at CEC

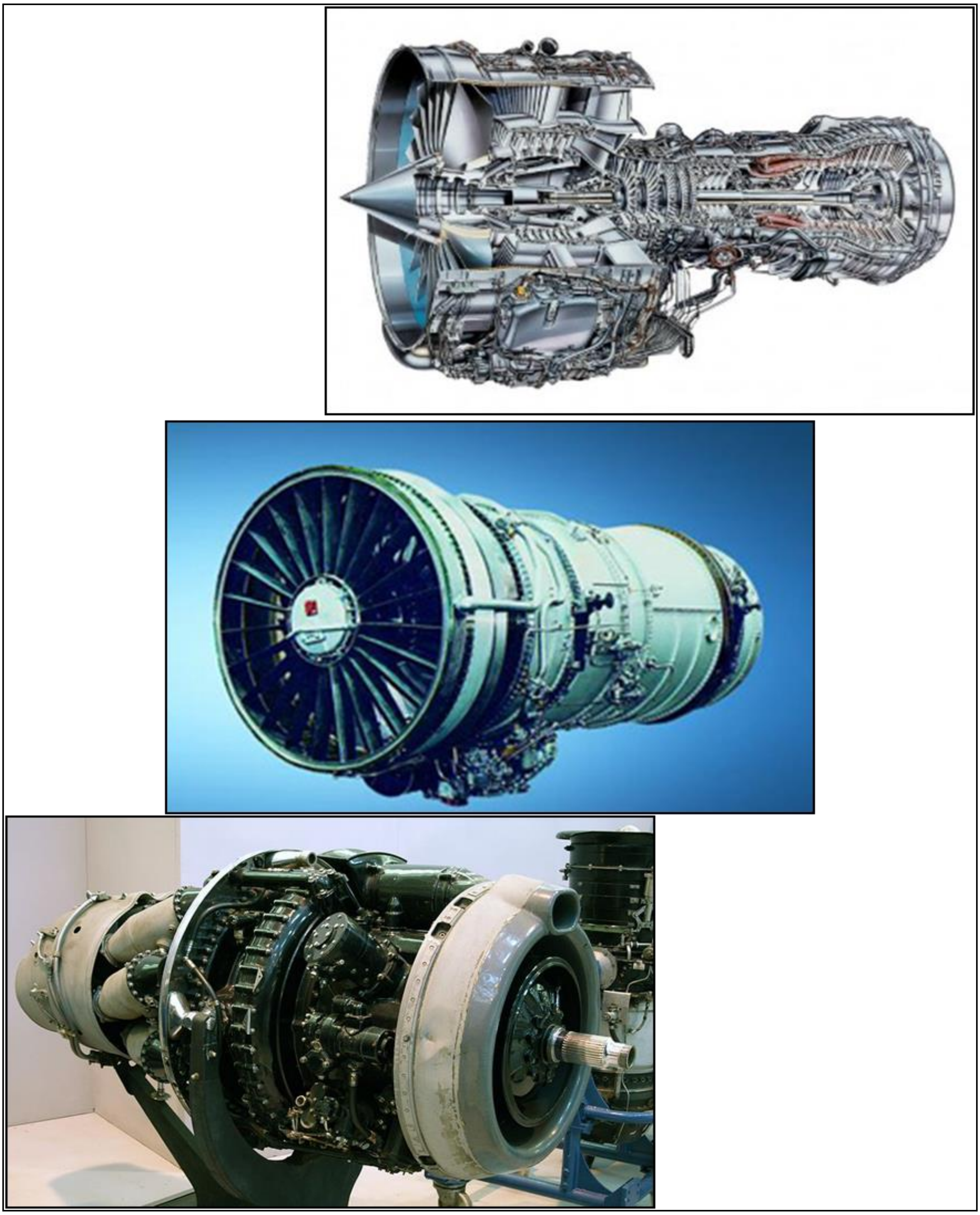


Figure 51: Engines currently remanufactured at CEC showing the V2500, JT8D and Rolls Royce Dart respectively

Appendix C: Standard operating procedure for EII

Overview

This project aims to add a supplementary index to current Value Stream Mapping methods in the form of an environmental impact index. The addition to the current VSM is an extra data box entry called an Environmental Impact Index (EII). The data box obtains its data from the excel calculator tool created. The tool aims to capture an appropriate selection and amount of environmental factors that build a complete environmental waste impact profile. The factors currently selected are:

- Carbon Footprint
- Perceived impact of waste
- Cost to remove waste
- Volume of waste remaining at location x CEC normal level risk register amount
- Volume of waste removed from location x CEC normal level risk register amount

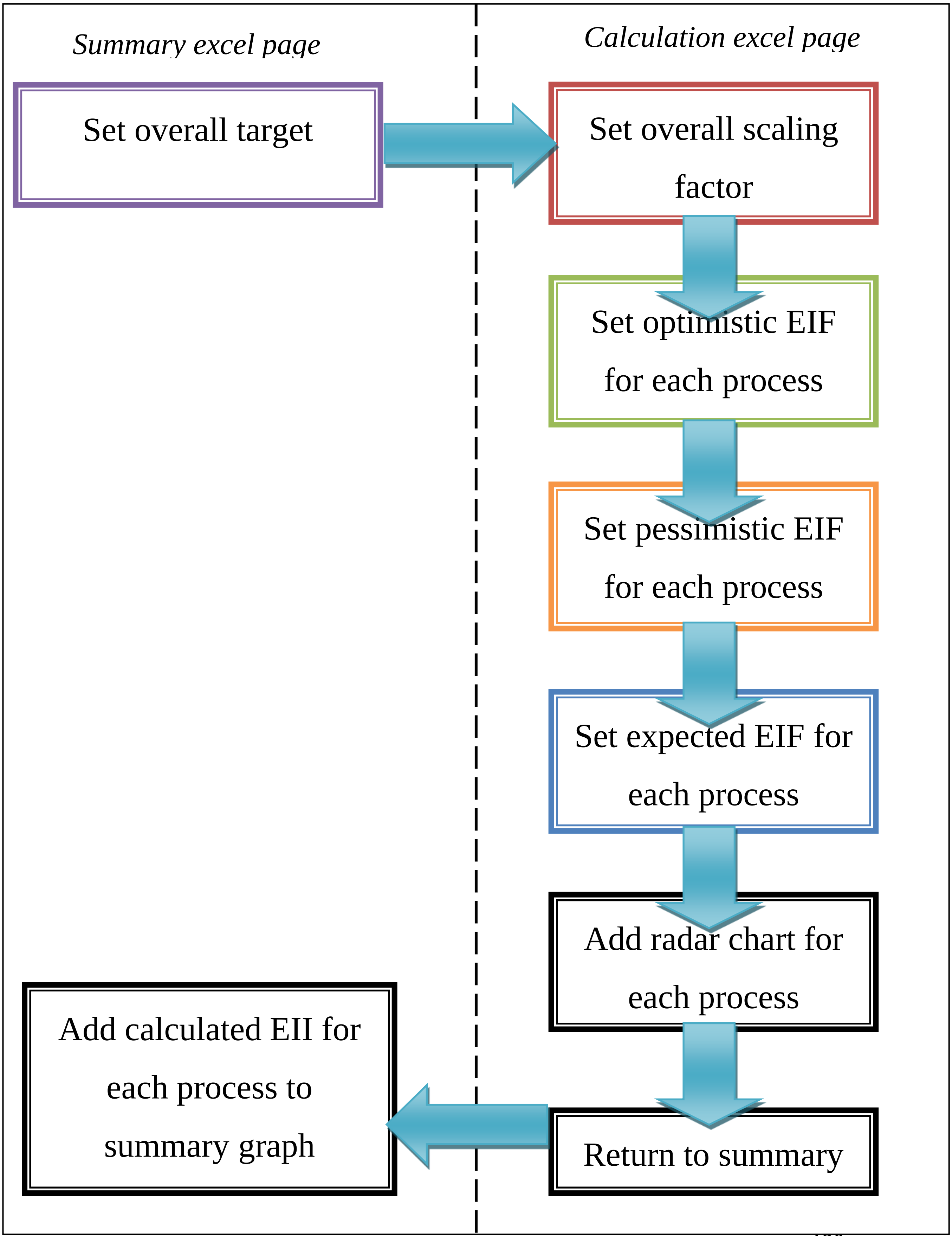
The waste factors currently used can be easily removed, modified, replaced or added to at any time.

How it works

- Normal conventional Value Stream Mapping method is applied to chosen a value stream.
- Whilst time data is entered into current state map, environmental factors are also considered.
- Excel calculator tool is used to calculate Environmental Impact Index (EII) for each process.
- A Radar chart is used to help identify high waste impact processes and corresponding environmental Kaizen initiatives.
- A Kaizen is applied as per normal for time domain, and applied again in terms of environmental waste impact domain.

What can be done for Non-Value Added activities / time, can easily be done for environmental waste impact analysis.

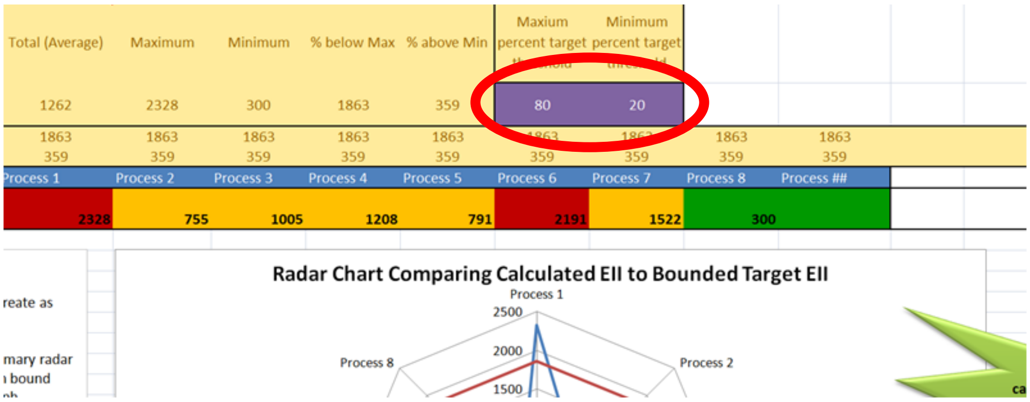
Diagram illustrating process steps



<u>Step by step process description – Standard user procedure</u>

<u>Summary excel page</u>

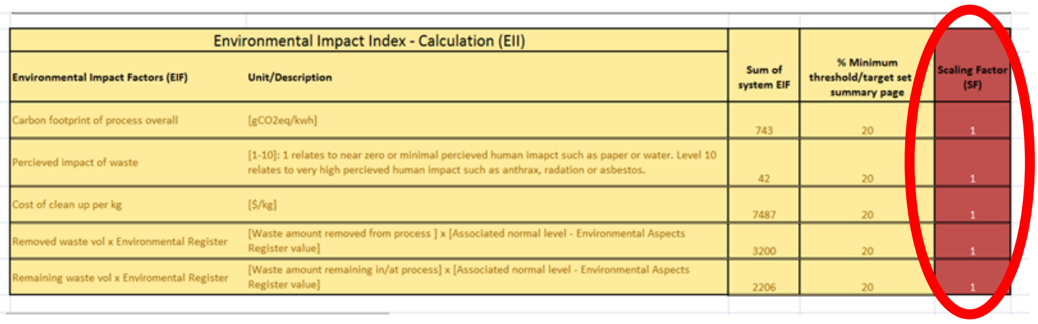
1) Start on Summary excel calculation page. Determine the maximum and minimum percent threshold bounds. These simply create a high and low boundary to help highlight good, neutral and bad processes. For ease of use, these thresholds will be set at 80% and 20% initially.



2) Go to calculation page.

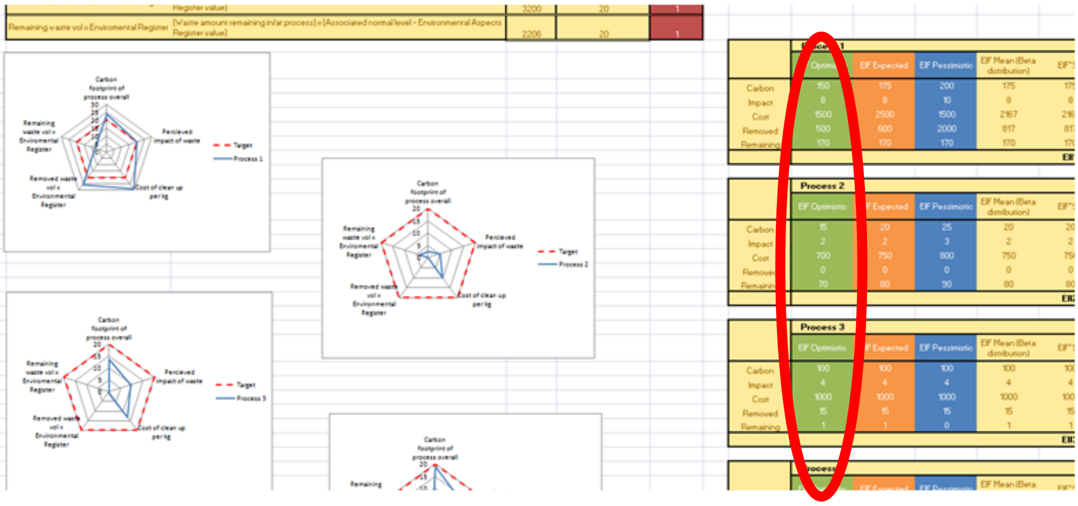
<u>Calculation excel page</u>

3) The scaling factor is used only when greater emphasis is required on a particular environmental factor. An example would be to specifically target high carbon footprint processes by increasing the scaling factor to 100. Add overall **Scaling Factors (SF)** if required starting at a value of 1 and raising in increments of 10, otherwise will remain 1.

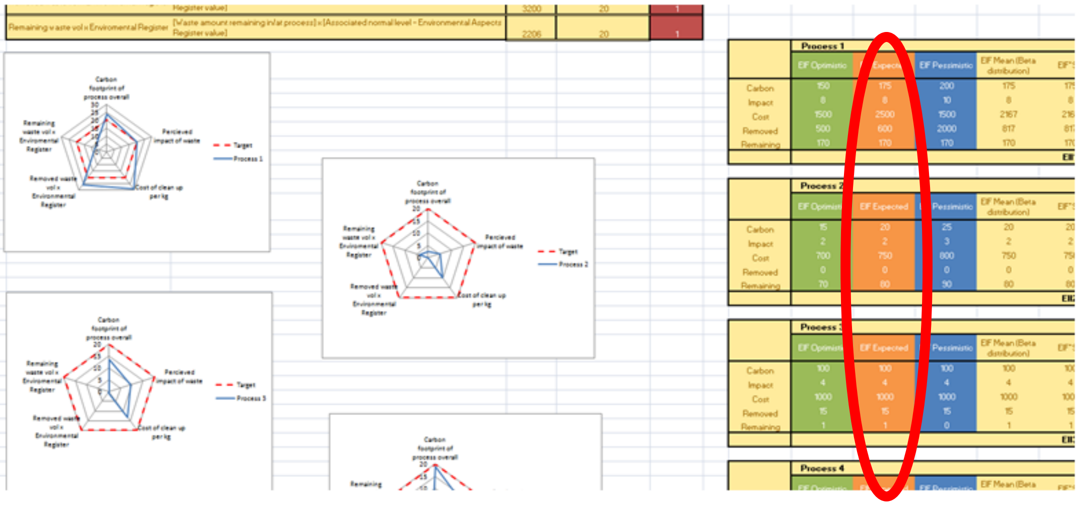


Environmental Impact Index - Calculation (EII)		Sum of system EIF	% Minimum threshold/target set summary page	Scaling Factor (SF)
Environmental Impact Factors (EIF)	**Unit/Description**			
Carbon footprint of process overall	[gCO2eq/kwh]	743	20	1
Percieved impact of waste	[1-10]: 1 relates to near zero or minimal percieved human imapct such as paper or water. Level 10 relates to very high percieved human impact such as anthrax, radation or asbestos.	42	20	1
Cost of clean up per kg	[$/kg]	7487	20	1
Removed waste vol x Environmental Register	[Waste amount removed from process] x [Associated normal level - Environmental Aspects Register value]	3200	20	1
Remaining waste vol x Enviromental Register	[Waste amount remaining in/at process] x [Associated normal level - Environmental Aspects Register value]	2206	20	1

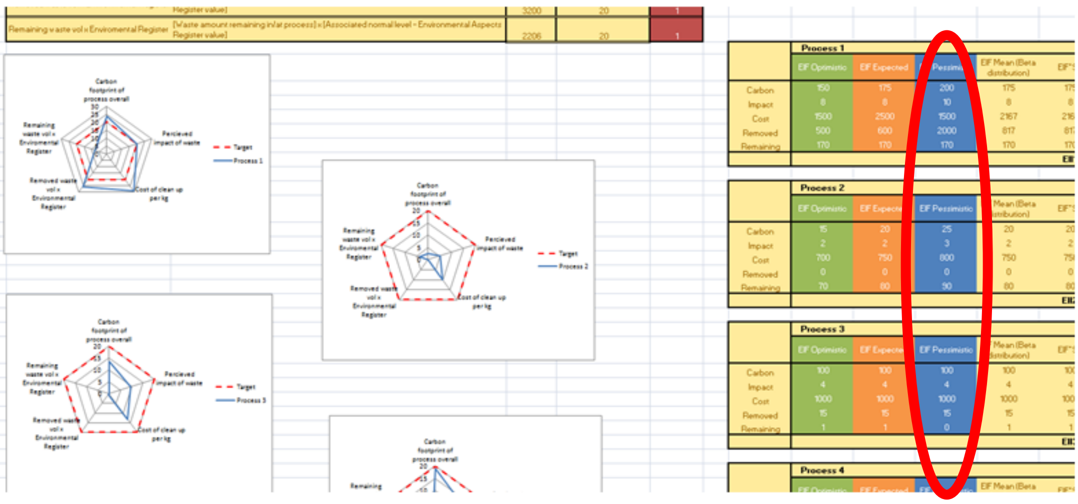
4) The next step is to add the data relating to each environmental factor. If the exact value is known enter in the same value for each column, otherwise use three estimations of worse case, expected and best case scenario. Add **Optimistic Environmental Impact Factors (EIFs)** Green column.



5) Add **Expected EIFs,** Orange column.

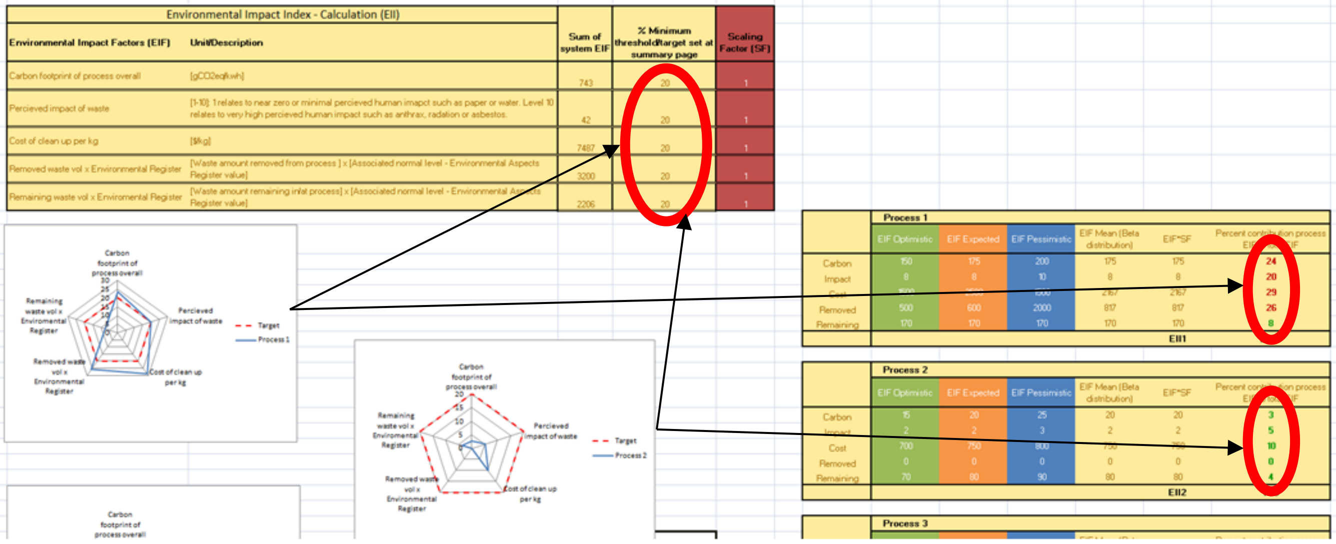


6) Add **Pessimistic EIFs**, Blue column.



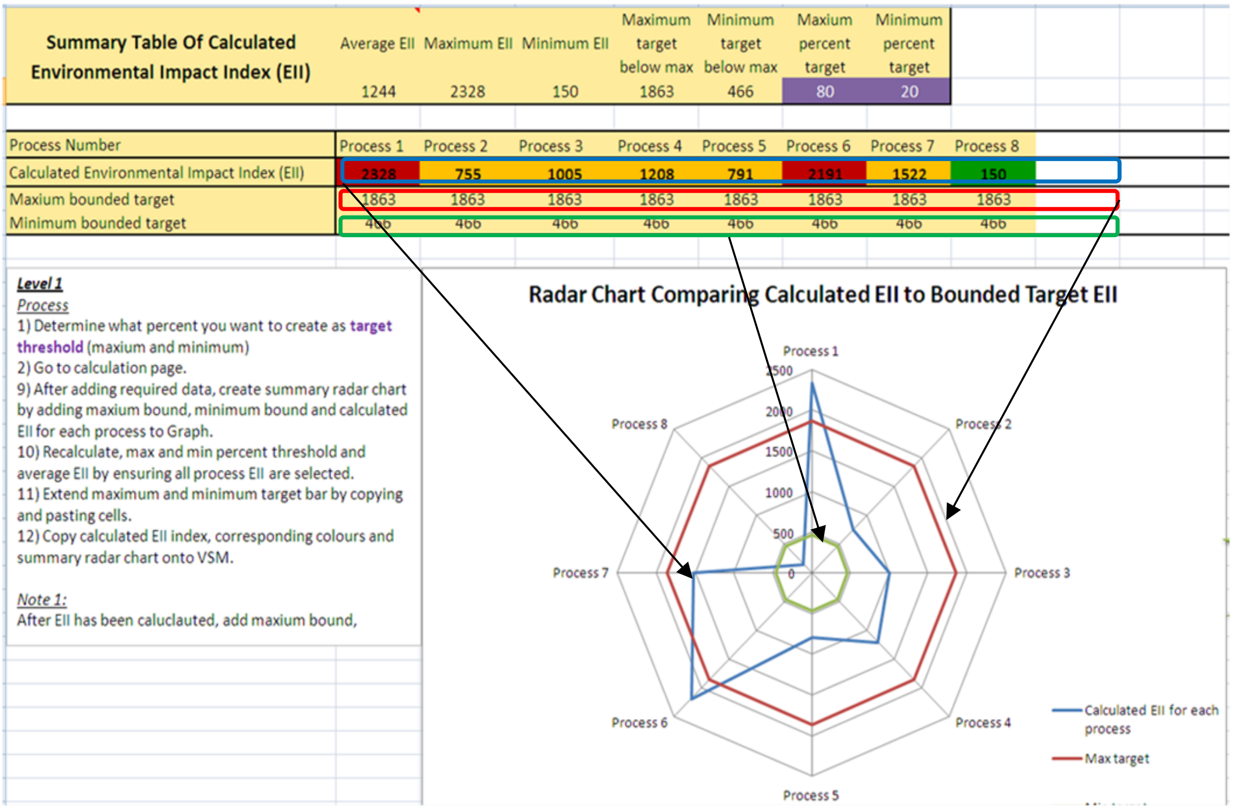
7) Radar charts are used as a visual display to show the amount of each waste factor in a process. Add radar charts for each new process by selecting the contribution of the environmental factor for an

individual process and plotting against the already calculated threshold (in this case 20%) value at the top of the page.



8) Return to Summary page

9) After adding the data, create a summary radar chart. This is used to quickly highlight poor performing processes that require Kaizen initiatives. The chart is created by the max EII, min EII and process EII rows to the radar chart.



11) Add additional cells by copying and pasting previous processes as required.

12) Copy calculated EII, corresponding colours and summary radar chart onto VSM.

Appendix D: Post implementation questionnaire

Research project – Environmental Value Stream Mapping

Department of Mechanical Engineering
University of Canterbury
Te Whare Wānanga o Waitaha   Telephone: +64-3-364 2987 x6571
Private Bag 4800   Facsimile: +64-3-364 2078
Christchurch 8020, New Zealand   Website: www.mech.canterbury.ac.nz

Information Sheet

The objective of this survey is to determine the usability of the proposed environmental impact analysis tool along with the extent to which the methodology accurately portrays the environmental impact of manufacturing and information processes.

Welcome: Dear Survey Taker, you are invited to participate in a research study conducted by Timothy Roosen (Masters of Engineering student) and supervised by Dr. Dirk Pons (dirk.pons@canterbury.ac.nz) from the Mechanical Engineering Department of the University of Canterbury in Christchurch. The interview is intended to be either face to face or by questionnaire (paper/electronic) if required. The purpose of the study is to amalgamate the concepts of conventional environmental waste management analysis tools with lean manufacturing waste principles, specifically Value Stream Mapping. This will take the form of a composite index of environmental waste impact factors to be used in tandem with Value Stream Mapping, a lean manufacturing tool currently used at the Pratt and Whitney, Christchurch Engine Centre.

Publication: The results of this research will be published in an academic report and possibly also a paper and presentation to a learned society/professional institution. We expect that the results will have implications for practitioners in the field of Environmental Health and Safety, particularly those involved with the Achieving Competitive Advantage (ACE) programme at the Christchurch Engine Centre.

Potential risks: There are no foreseeable risks or discomfort associated with this study. The project has been reviewed and approved by the University of Canterbury Human Ethics Committee low risk process.

Confidential: Any information that you provide will be treated as confidential. Only the principal researcher and the supervisor will have access to raw data. All answers and information from participants will be collected anonymously. Data will only be presented in aggregated form in research reports, presentations, and papers. There will be no disclosure of individually identifiable data to other parties. Names and contact details are not collected as part of the survey. The survey data will be stored on password-protected computers.

Withdrawal: You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you do not want to answer. This proposal has been reviewed and approved by the Department of Mechanical Engineering, University of Canterbury. If you have

Research project – Environmental Value Stream Mapping

Department of Mechanical Engineering
University of Canterbury
Te Whare Wānganga o Waitaha Telephone: +64-3-364 2987 x6571
Private Bag 4800 Facsimile: +64-3-364 2078
Christchurch 8020, New Zealand Website: www.mech.canterbury.ac.nz

any questions or concerns about this research, please contact the supervisor Dr. Dirk Pons (dirk.pons@canterbury.ac.nz)

Instructions (please read carefully): It is possible that not all questions apply to your particular case. Whenever you feel that the question is not relevant to you (i.e. not applicable), please SKIP the question. You may find that some questions are relevant to your situation, but you do not possess sufficient information to answer them. In that instance, please select the option I DON'T KNOW where it is available. One question follows, this being the informed consent. Thereafter the main survey follows.

Research project – Environmental Value Stream Mapping

Department of Mechanical Engineering
University of Canterbury
Te Whare Wānganga o Waitaha   Telephone: +64-3-364 2987 x6571
Private Bag 4800   Facsimile: +64-3-364 2078
Christchurch 8020, New Zealand   Website: www.mech.canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Participant Consent

- I have read and understood the description of the above-mentioned project.
- I understand that my participation will involve an online questionnaire
- I fully accept that by completing the questionnaires I am giving my consent to participate in this online research study. Ticking the 'accept' box as shown below indicates that I understand and agree to the research conditions.
- I also understand and am satisfied with all the measures that will be taken to protect my identity and ensure my interests are protected.
- I agree to publication of results, with the understanding that my anonymity will be preserved.
- I am aware that the project has been reviewed and approved by the University of Canterbury Human Ethics Committee low risk process.

--   --
Name   Signature

Date

Research project – Environmental Value Stream Mapping

Department of Mechanical Engineering
University of Canterbury
Te Whare Wānanga o Waitaha Telephone: +64-3-364 2987 x6571
Private Bag 4800 Facsimile: +64-3-364 2078
Christchurch 8020, New Zealand Website: www.mech.canterbury.ac.nz

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Questionnaire: Integrated Value Stream Mapping and environmental waste impact methodology

(Extent measured as scale from 1 to 5. One equating to a low extent and 5 equating to a high extent).

1. To what extent do you think it is important to measure environment waste impacts?

   (1 – Low extent, 5 - High extent)

2. How many times have you used the environmental impact index tool?

3. To what extent do you think the tool was successful in prompting new thinking and continuous improvement?

   (1 – Low extent, 5- High extent)

4. To what extent do you think the method was effective at identifying/reduccing environmental waste?

   (1 – Low extent, 5- High extent)

5. What environmental factor did you find most appropriate?

   (1 – Low extent, 5- High extent)

6. What environmental factor did you find least appropriate (which would you add)?

   (1 – Low extent, 5- High extent)

7. What did you find difficult? (Or if you could change one thing what would it be?)

Thank you very much for your time!

Appendix E: Implementation radar charts for annulus filler value stream

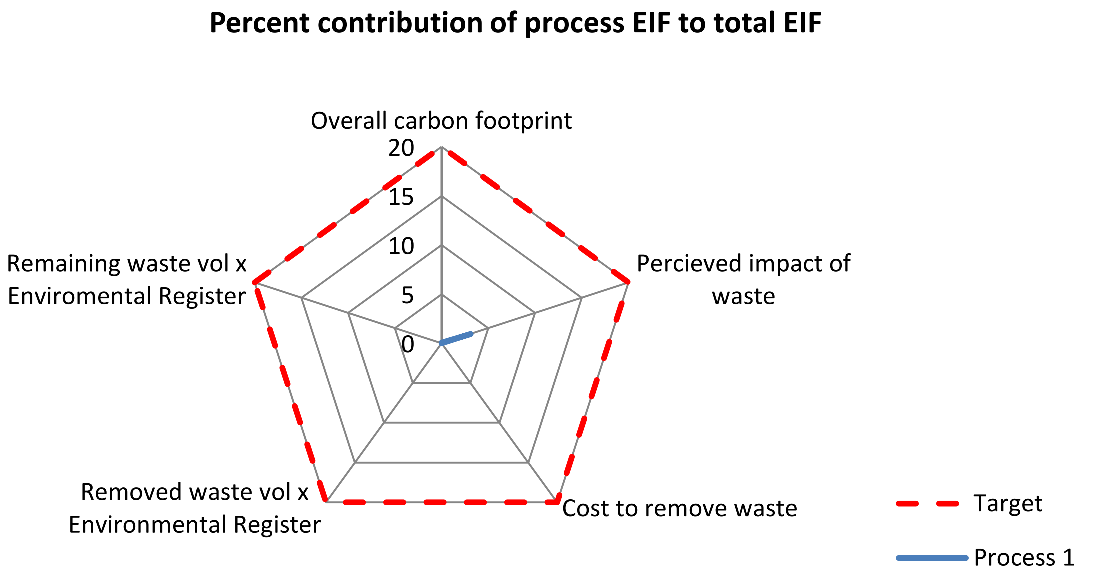


Figure 52: Process one environmental impact breakdown according to measured environmental impact factors

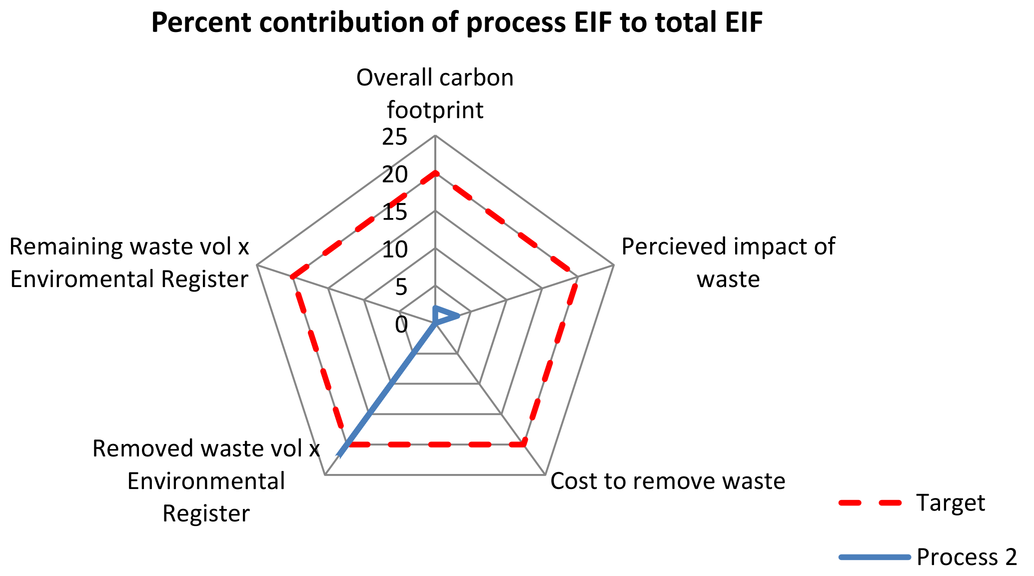


Figure 53: Process two environmental impact breakdown according to measured environmental impact factors

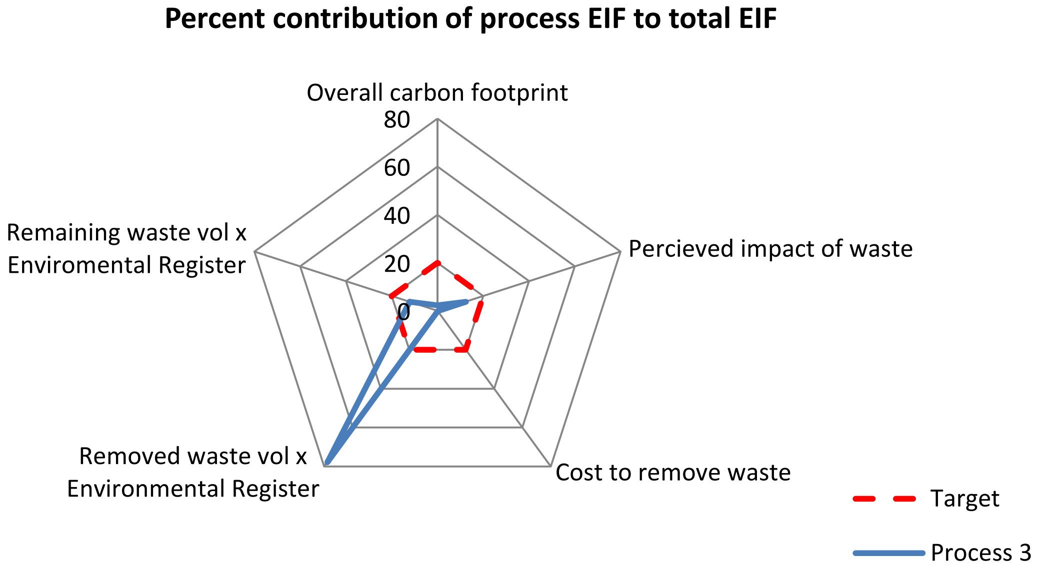


Figure 54: Process three environmental impact breakdown according to measured environmental impact factors

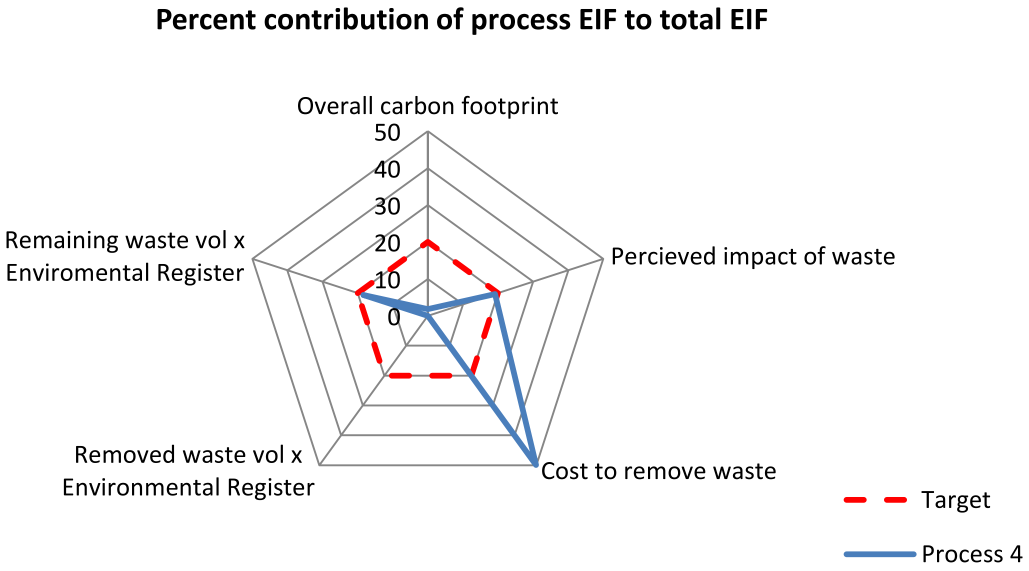


Figure 55: Process four environmental impact breakdown according to measured environmental impact factors

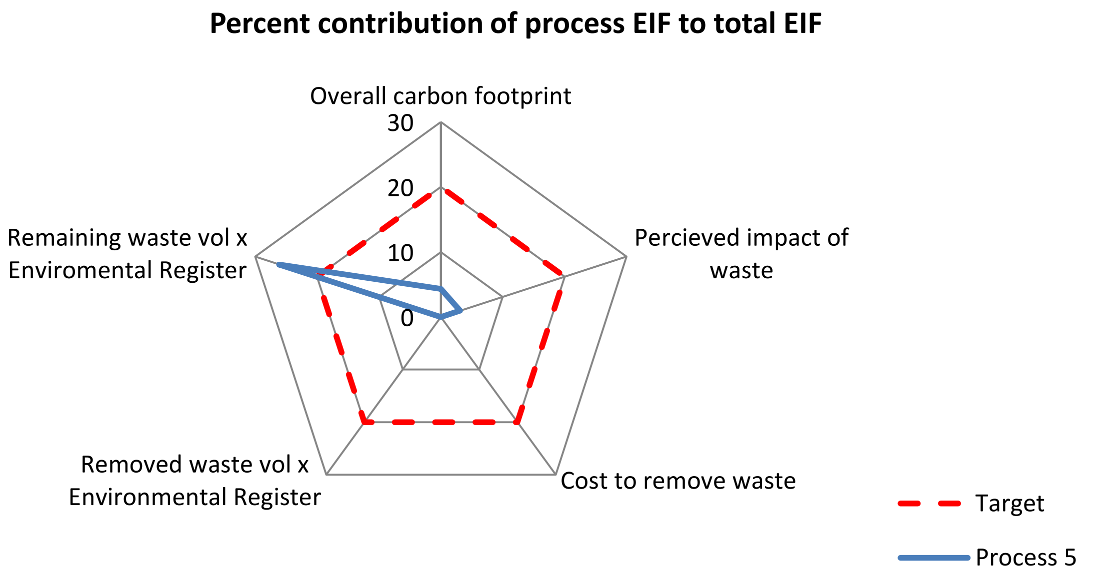


Figure 56: Process five environmental impact breakdown according to measured environmental impact factors

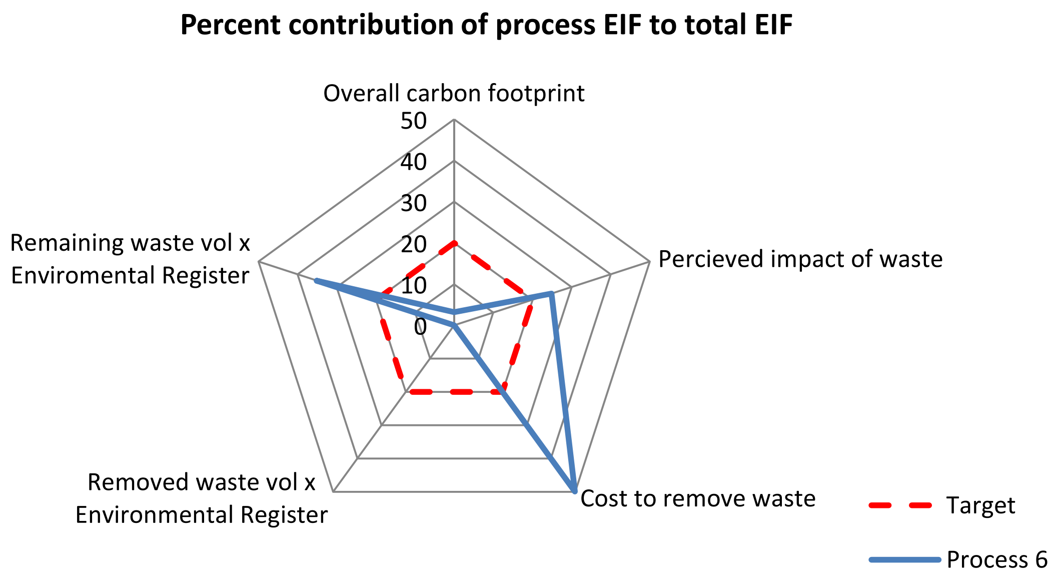


Figure 57: Process six environmental impact breakdown according to measured environmental impact factors

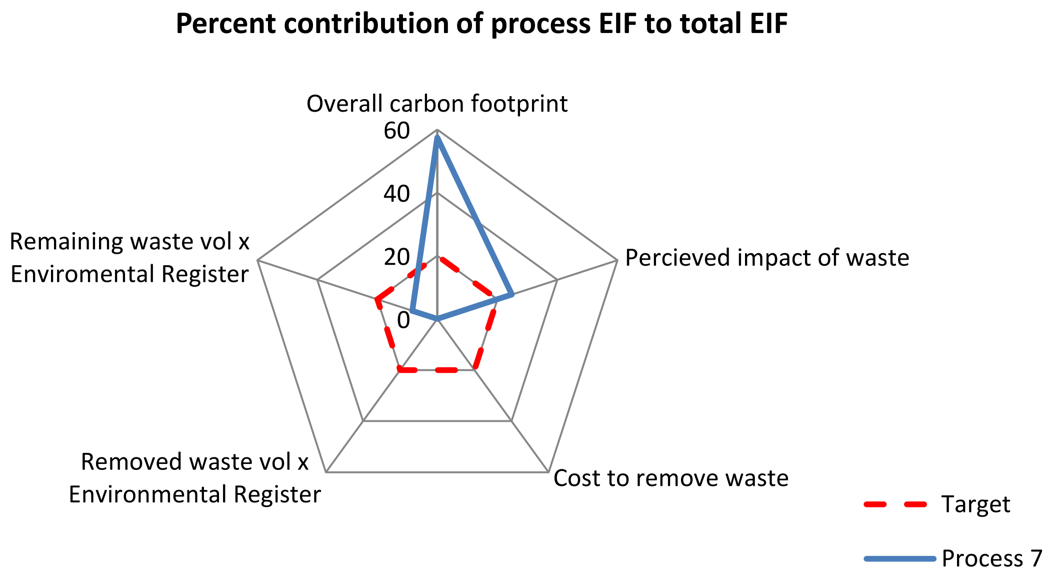


Figure 58: Process seven environmental impact breakdown according to measured environmental impact factors

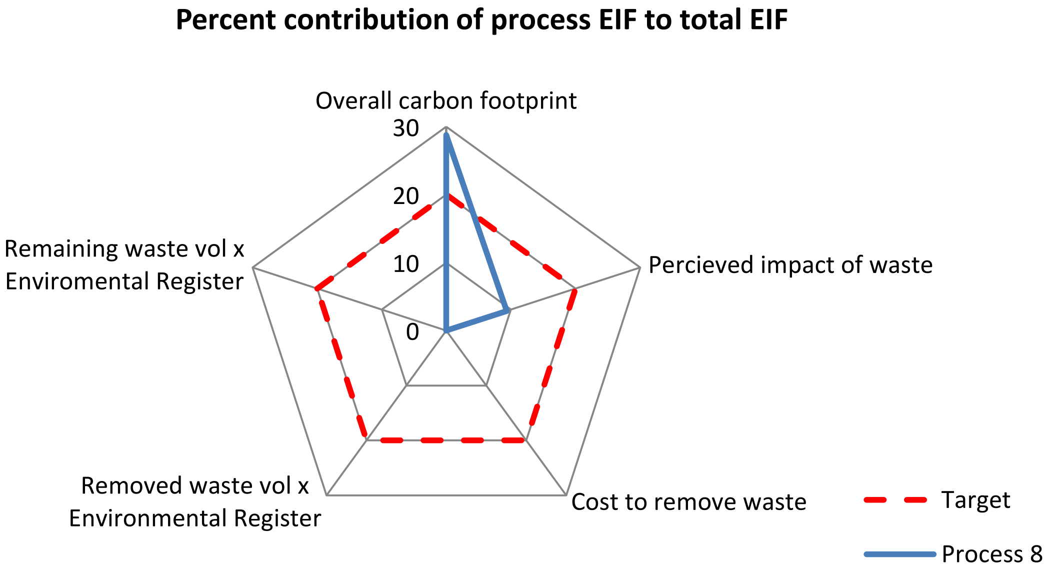


Figure 59: Process eight environmental impact breakdown according to measured environmental impact factors

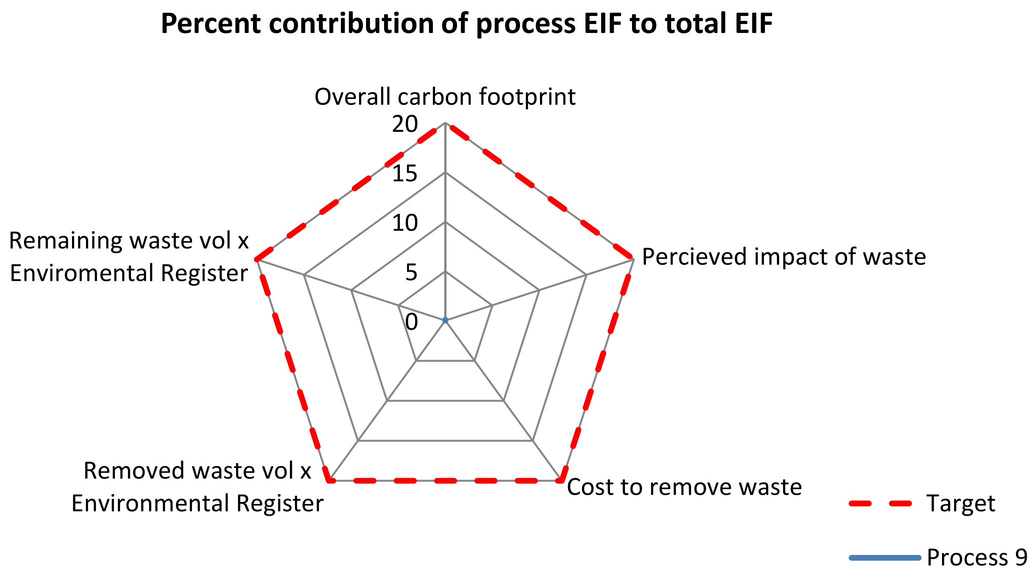
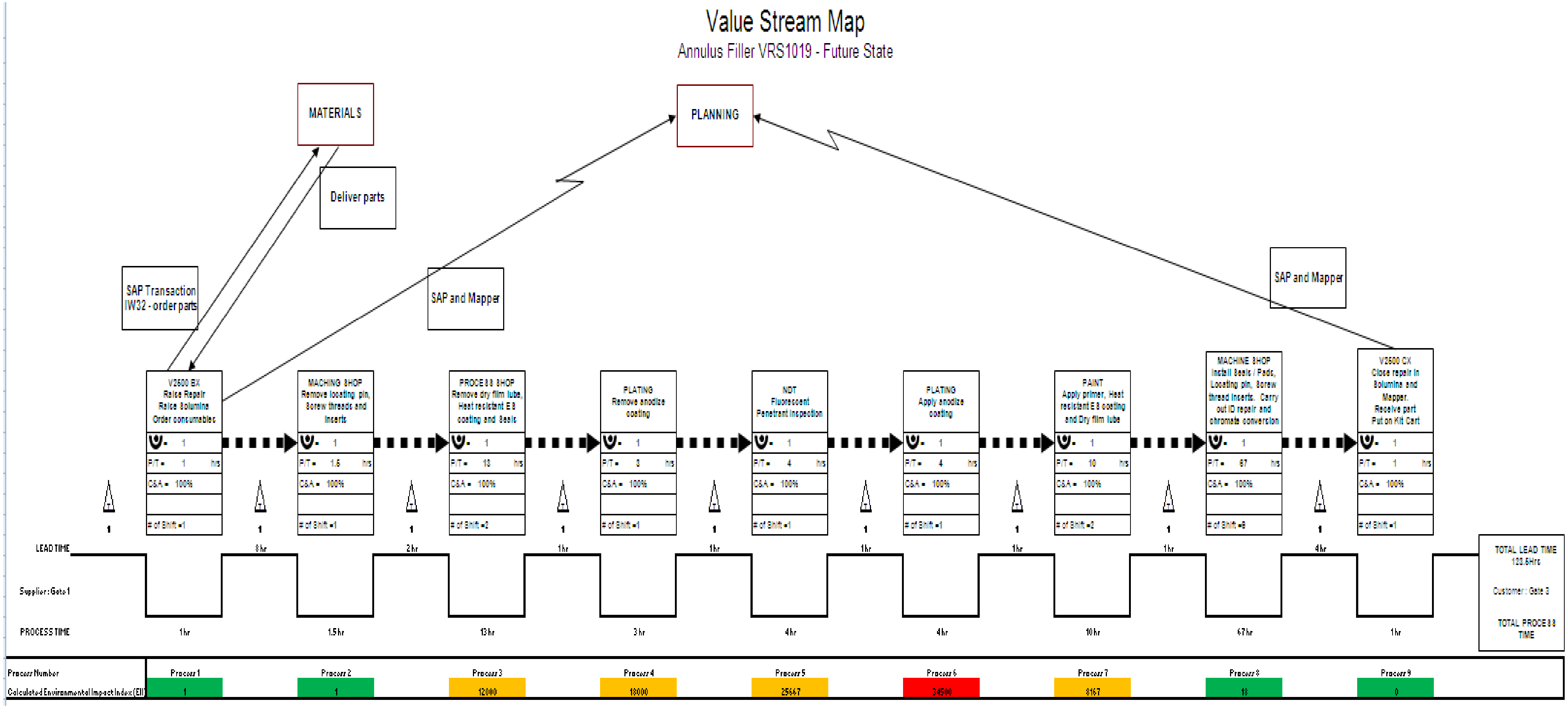


Figure 60: Process nine environmental impact breakdown according to measured environmental impact factors

Appendix F: Implemented EVSM on annuls filler future state value stream



Appendix G: Detailed implementation data for original Annulus Filler value stream

Table 11: Summary of environmental impact index table for Annulus Filler implementation

Summary Table Of Calculated Environmental Impact Index (EII)	Average EII	Maximum EII	Minimum EII	Maximum target below max EII	Minimum target below max EII	Maximum percent target	Minimum percent target
	10928	34500	0	27600	6900	80	20

Table 12: Environmental impact index for each process for Annulus filler implementation

Process Number	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7	Process 8	Process 9
Calculated Environmental Impact Index (EII)	**1**	**1**	**12000**	**18000**	**25667**	**34500**	**8167**	**18**	**0**
Maximum bounded target	27600	27600	27600	27600	27600	27600	27600	27600	27600
Minimum bounded target	6900	6900	6900	6900	6900	6900	6900	6900	6900
Percent below or above max target	-99.996	-99.995	-56.522	-34.782	-7.005	25.000	-70.411	-99.936	99.9998

Table 13: Initial scaling factor, sum of system information and target percent thresholds for Annulus Filler implementation

Environmental Impact Index - Calculation (EII)		**Sum of system EIF**	**% threshold/target set at summary page**	**Scaling Factor (SF)**
Environmental Impact Factors (EIF)	**Unit/Description**			
Overall carbon footprint	[kgCO2eq/kwh]	53.2	20	1

Perceived impact of waste	[LEVELS 1-10]: **Level 1** relates to near zero or minimal perceived human impact such as paper or storm water. **Level 5** relates to medium level of perceived human impact such as sewage. **Level 10** relates to very high perceived human impact such as anthrax, radiation or asbestos.	32.2	20	1
Cost to remove waste	[$/kg] or [$/L]	202.3	20	1
Removed waste vol x Environmental Register	[Waste amount removed from process] x [Associated normal level - Environmental Aspects Register value]	0.5	20	1
Remaining waste vol x Environmental Register	[Waste amount remaining in/at process] x [Associated normal level - Environmental Aspects Register value]	98341.6	20	1

Table 14: Step by step process break down and environmental impact index calculations for Annulus Filler implementation

	Process 1: V2500 BX. Raise repair.						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	0.043	0.043	0.043	0	0	**0.1**	0.00
Impact	1	1	1	1	1	**3.1**	0.00
Cost	0	0	0	0	0	**0.0**	0.00
Removed	0	0	0	0	0	**0.0**	0.00
Remaining	0	0	0	0	0	**0.0**	0.00
Eii						**1.0**	
	Process 2: Machine shop remove locating pin, screw threads and inserts						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.09	1.09	1.09	1	1	**2.1**	0.00

	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Impact	1	1	1	1	1	**3.1**	0.00
Cost	0	0	0	0	0	**0.0**	0.00
Removed	0.11	0.11	0.11	0	0	**22.2**	0.00
Remaining	0	0	0	0	0	**0.0**	0.00
Eii						**1.5**	
	Process 3: Process shop: Remove DFL, heat resistant ES coating and seals						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.23	1.23	1.23	1	1	**2.3**	0.00
Impact	3	4	5	4	4	**12.4**	0.82
Cost	0.25	0.25	0.75	0	0	**0.2**	0.24
Removed	0.33	0.33	0.66	0	0	**77.8**	0.16
Remaining	12000	12000	12000	12000	12000	**12.2**	0.00
Eii						**12000.0**	
	Process 4: Plating: Remove anodise coating						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	0.95	0.95	0.95	1	1	**1.8**	0.00
Impact	6	6	7	6	6	**19.2**	0.47
Cost	101	101	101	101	101	**49.9**	0.00
Removed	0	0	0	0	0	**0.0**	0.00
Remaining	18000	18000	18000	18000	18000	**18.3**	0.00
Eii						**18000.3**	
	Process 5: NDT: FPI						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total	Accuracy/ Standard deviation

						EIF	of estimates
Carbon	2.29	2.29	2.29	2	2	**4.3**	0.00
Impact	1.00	1.00	1.00	1	1	**3.1**	0.00
Cost	0.00	0.00	0.00	0	0	**0.0**	0.00
Removed	0.00	0.00	0.00	0	0	**0.0**	0.00
Remaining	14000.00	28000.00	28000.00	25667	25667	**26.1**	6599.66
Eii						**25666.7**	
	Process 6: Plating: Apply anodised coating						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.7	1.7	1.7	2	2	**3.2**	0.00
Impact	7.0	8.0	9.0	8	8	**24.9**	0.82
Cost	101.0	101.0	101.0	101	101	**49.9**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	27000.0	36000.0	36000.0	34500	34500	**35.1**	4242.64
Eii						**34500.1**	
	Process 7: Paint: heat res coat, DFL						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	30.5	30.5	30.5	31	31	**57.4**	0.00
Impact	8.0	8.0	8.0	8	8	**24.9**	0.00
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	7000.0	7000.0	14000.0	8167	8167	**8.3**	3299.83
Eii						**8166.7**	

	Process 8: Machine shop: Install seals , pads, locating pin, inserts, ID repair and chromate conversion						Accuracy/ Standard deviation of estimates
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	
Carbon	15.3	15.3	15.3	15	15	**28.8**	0.00
Impact	2.0	3.0	4.0	3	3	**9.3**	0.82
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	4.5	9.0	9.0	8	8	**0.0**	2.12
Eii						**17.7**	
	Process 9: V2500 CX: Close repair, put on kit cart						Accuracy/ Standard deviation of estimates
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	
Carbon	0.04	0.04	0.04	0.0	0	**0.1**	0.00
Impact	0.0	0.0	0.0	0	0	**0.0**	0.00
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	0.0	0.0	0.0	0	0	**0.0**	0.00
Eii						**0.0**	

Table 15: Carbon footprint conversion calculators

Computer use	
Number of people	
Time (hours)	
Power (kw)	0.2

Grid elec gCO2e (per kWh)	0.215
kgCO2eq	**0.043**
Lights	
Number of lights	
Time (hours)	
Bulb/Tube rating (kW)	0.058
Grid elec kgCO2e (per kWh)	0.215
kgCO2eq	**0.00**

Truck	
Distance (km)	
Fuel efficiency (L/Km)	0.2
Diesel -- kgCO2e (per L)	2.68
kgCO2eq	**0.00**
General elec equip	
Time (hours)	
Power rating (kW)	
Grid elec -- kgCO2e (per kWh)	0.215
kgCO2eq	**0.00**
Basic electricity units	
Current (I/Amps)	
Volts (V)	
Time (hours)	
Grid elec -- kgCO2e (per kWh)	0.215
kgCO2eq	**0.00**
LPG (source from boiler)	
Average volume LPG (m3) per month	4000

Hours in a month	720
Total number of heated tanks	12
Number of heated cleaning tanks used	1
Time (hours)	1.5
LPG-- kgCO2eq (per L)	1.775
kgCO2eq	**1.23**

Appendix H: Detailed implementation data for alternatively scaled annulus filler value stream

Table 16: Summary data for alternately scale annulus filler value stream (scaled system)

Summary Table Of Calculated Environmental Impact Index (EII)	Average EII	Maximum EII	Minimum EII	Maximum target below max EII	Minimum target below max EII	Maximum percent target	Minimum percent target
	33	107	0	86	21	80	20

Table 17: Environmental impact index for each process for Annulus filler implementation (scaled system)

Process Number	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7	Process 8	Process 9
Calculated Environmental Impact Index (EII)	**1**	**1**	**13**	**103**	**26**	**107**	**33**	**16**	**0**
Maximum bounded target	86	86	86	86	86	86	86	86	86
Minimum bounded target	21	21	21	21	21	21	21	21	21
Percent below or above max target	-98.8	-98.3	-85.2	20.0	-69.9	25.0	-61.9	-81.8	-99.9

Table 18: Initial scaling factor, sum of system information and target percent thresholds for Annulus Filler implementation (scaled system)

Environmental Impact Index - Calculation (EII)		**Sum of system EIF**	**% threshold/target set at summary page**	**Scaling Factor (SF)**
Environmental Impact Factors (EIF)	**Unit/Description**			
Overall carbon footprint	[kgCO2eq/kwh]	53.2	20	1

Perceived impact of waste	[LEVELS 1-10]: **Level 1** relates to near zero or minimal perceived human impact such as paper or storm water. **Level 5** relates to medium level of perceived human impact such as sewage. **Level 10** relates to very high perceived human impact such as anthrax, radiation or asbestos.	32.2	20	1
Cost to remove waste	[$/kg] or [$/L]	202.3	20	1
Removed waste vol x Environmental Register	[Waste amount removed from process] x [Associated normal level - Environmental Aspects Register value]	0.5	20	0.001
Remaining waste vol x Environmental Register	[Waste amount remaining in/at process] x [Associated normal level - Environmental Aspects Register value]	98341.6	20	0.001

Table 19: Step by step process break down and environmental impact index calculations for Annulus Filler implementation (scaled system)

	Process 1: V2500 BX. Raise repair.						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	0.043	0.043	0.043	0	0	**0.1**	0.00
Impact	1	1	1	1	1	**3.1**	0.00
Cost	0	0	0	0	0	**0.0**	0.00
Removed	0	0	0	0	0	**0.0**	0.00
Remaining	0	0	0	0	0	**0.0**	0.00
Eii						**1.0**	
	Process 2: Machine shop remove locating pin, screw threads and inserts						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.09	1.09	1.09	1	1	**2.1**	0.00
Impact	1	1	1	1	1	**3.1**	0.00

	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Cost	0	0	0	0	0	**0.0**	0.00
Removed	0.11	0.11	0.11	0	0	**22.2**	0.00
Remaining	0	0	0	0	0	**0.0**	0.00
Eii						**1.5**	
	Process 3: Process shop: Remove DFL, heat resistant ES coating and seals						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.23	1.23	1.23	1	1	**2.3**	0.00
Impact	3	4	5	4	4	**12.4**	0.82
Cost	0.25	0.25	0.75	0	0	**0.2**	0.24
Removed	0.33	0.33	0.66	0	0	**77.8**	0.16
Remaining	12000	12000	12000	12000	12	**12.2**	0.00
Eii						**12.7**	
	Process 4: Plating: Remove anodise coating						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	0.95	0.95	0.95	1	1	**1.8**	0.00
Impact	6	6	7	6	6	**19.2**	0.47
Cost	101	101	101	101	101	**49.9**	0.00
Removed	0	0	0	0	0	**0.0**	0.00
Remaining	18000	18000	18000	18000	18	**18.3**	0.00
Eii						**102.8**	
	Process 5: NDT: FPI						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates

Carbon	2.29	2.29	2.29	2	2	**4.3**	0.00
Impact	1.00	1.00	1.00	1	1	**3.1**	0.00
Cost	0.00	0.00	0.00	0	0	**0.0**	0.00
Removed	0.00	0.00	0.00	0	0	**0.0**	0.00
Remaining	14000.00	28000.00	28000.00	25667	26	**26.1**	6599.66
Eii						**25.8**	
	Process 6: Plating: Apply anodised coating						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	1.7	1.7	1.7	2	2	**3.2**	0.00
Impact	7.0	8.0	9.0	8	8	**24.9**	0.82
Cost	101.0	101.0	101.0	101	101	**49.9**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	27000.0	36000.0	36000.0	34500	35	**35.1**	4242.64
Eii						**107.0**	
	Process 7: Paint: heat res coat, DFL						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	30.5	30.5	30.5	31	31	**57.4**	0.00
Impact	8.0	8.0	8.0	8	8	**24.9**	0.00
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	7000.0	7000.0	14000.0	8167	8	**8.3**	3299.83
Eii						**32.6**	

	Process 8: Machine shop: Install seals , pads, locating pin, inserts, ID repair and chromate conversion						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	15.3	15.3	15.3	15	15	**28.8**	0.00
Impact	2.0	3.0	4.0	3	3	**9.3**	0.82
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	4.5	9.0	9.0	8	0	**0.0**	2.12
Eii						**15.6**	

	Process 9: V2500 CX: Close repair, put on kit cart						
	EIF Optimistic	EIF Expected	EIF Pessimistic	EIF_Mean	EIF*SF	Percent contribution process EIF to total EIF	Accuracy/ Standard deviation of estimates
Carbon	0.04	0.04	0.04	0.0	0	**0.1**	0.00
Impact	0.0	0.0	0.0	0	0	**0.0**	0.00
Cost	0.0	0.0	0.0	0	0	**0.0**	0.00
Removed	0.0	0.0	0.0	0	0	**0.0**	0.00
Remaining	0.0	0.0	0.0	0	0	**0.0**	0.00
Eii						**0.0**	

Appendix I: Paper submitted to the Journal of Industrial Engineering

This is a copy of journal paper submitted and accepted by the the Journal of Industrial Engineering, Hindawi Publishing Corporation. Article currently in press to be published.

ENVIRONMENTALLY LEAN PRODUCTION: THE DEVELOPMENT AND INCORPORATION OF AN ENVIRONMENTAL IMPACT INDEX INTO VALUE STREAM MAPPING

Roosen T.J. [8] and Pons D.J.[9]

Abstract

Current concepts of environmental waste focus on the total production of waste from a plant or industrial setting and the subsequent consequences on the natural environment. Hence, there is an emphasis on containing waste within the industrial boundaries and applying a post-production process to clean it up. However, waste is generated by individual processes within the production and can be more effectively treated at this individual site level. Therefore, focussed management of environmental waste reduction requires that production engineers first know what the waste is, and where it is being generated. However, this is often simply not known with any accuracy. In addition, production plants are controlled and improved by lean methods. Current environmental waste methods lack integration with the lean methods and thus are not included in the continuous improvement cycles. Consequently, there is a need to include environmental waste impacts alongside the other lean wastes. This work develops just such an integrative a method, for environmental waste and Value Stream Mapping (VSM). This method was developed and tested in a re-manufacturing setting (i.e. Christchurch Engine Centre, Pratt and Whitney) and is able to represent a variety of environmental wastes. Specifically, it integrates aspects from the generic environmental standard ISO14001 through to an organisational environmental risk register. It provides integration within the VSM process which ensures that the established lean improvement programme (through the use of . Kaizen improvements) is focussed on specific environmental improvement actions. While the deployment used the factors of: carbon footprinting, perceived impact, costs to remediate and waste volumes (both removed from the process and residual); the method is capable of being generalised to n^{th} dimension environmental factors. It is thus able to represent a customised environmental waste index for any particular industry. Ambiguous user estimates of waste quantities were accommodated through PERT beta distributions. Several ways to represent the multi-dimensional environmental waste impact data were explored via industry focus group reviews and the preferred representation was designed to completion. The resulting method can be used by production staff to quantify and represent environmental impacts at the level of the individual processes, and aggregated to report wastes for the whole value stream. The method may also be used by executives to align organisational practices with strategic objectives for waste reduction.

1 Introduction

Lean practices seek to reduce waste in a production process. One of the more common lean management tools is the use of Value Stream Mapping (VSM). This tool analyses and delineates the time taken to complete a process with a particular emphasis on time that does not add value to the product. Hence identification occurs of Non-

[8] *Department of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand*

[9] *Please address correspondence to Dr Dirk Pons, Department of Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand. Email dirk.pons@canterbury.ac.nz*

Value–Added (NVA) time. VSM is used to reduce task time and subsequently reduce company monetary overheads.

VSM focuses on *time* as a wasted consumable. However lean processes as a whole are concerned with many other types of waste. Consequently organisations that seek to implement lean processes are typically required to use different lean tools to cover the various waste dimensions of their processes. This invariably means multiple systems with their own implementation, culture, and reporting processes. There is ongoing interest in developing integrated lean systems that avoid this duplication. One of these areas where better integration is desirable is between the time dimension as covered by VSM and the environmental waste aspects. Environmental waste is only weakly represented in current lean thinking, which tends to simply perceive waste as merely the excess (cost) of raw materials. However, from the environmental perspective, the type of waste is important because of the different toxicities and effects on the environment. There are also problems in getting any environmental waste considerations embedded in the production activities. For example, collecting data on environmental waste and its impact on the environment is the typical focus. Yet, there is a lack of vertical integration between the organisational data on environmental waste and the processes that originally created the waste (i.e. the source of the waste) as depicted in Figure 1. It is difficult to attribute environmental waste back to its source in the production process, and consequently difficult to apply the continuous improvement methods.

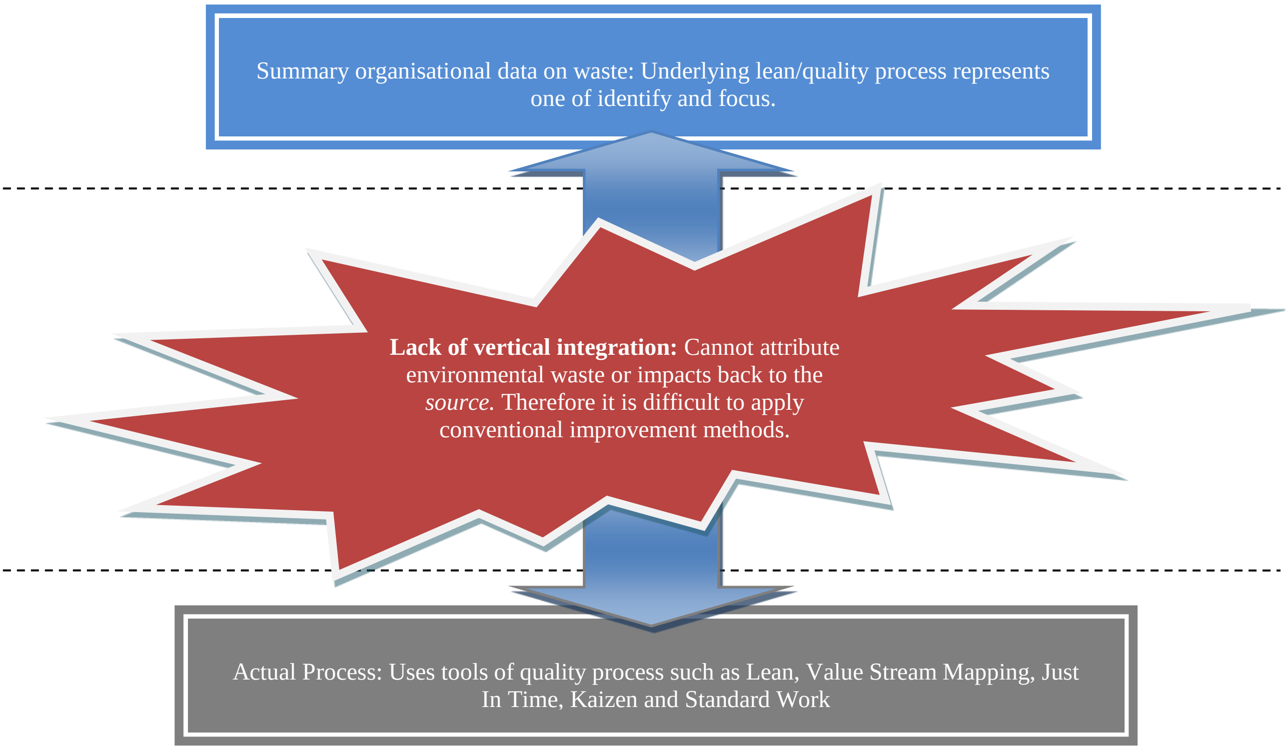


Figure 1: There is a lack of vertical integration between hard organisational data and process from which waste originated. This hinders the deployment of sustainability measures through the production system and down to the level of individual processes and operator work-teams.

This paper provides a method for the integration of environmental waste into VSM processes through the use of an embedded environmental impact analysis stream in an already established lean organisation. The particular area under examination is manufacturing and representative data from a case are provided.

2 Literature review

2.1 Lean manufacturing and the waste principle

The perception of waste reduction primarily focuses on the reduction of environmental impacts through the use of traditional waste management programmes. Waste management is most often associated with objects disposed or recycled.

In contrast, lean manufacturing aims to reduce costs of production by eliminating waste and Non-Value Added (NVA) activities and is a common underlying principle in many major businesses and production facilities around the world. Lean techniques developed in the creation of the Toyota Production System (TPS), which itself was an embodiment of previous production quality systems (Deming 1986; Womack, Jones et al. 1991; Womack and Jones 1996; Melton 2005; Abdulmalek and Rajgopal 2007).

In essence, lean manufacture seeks to preserve value within an organisation by emphasising reductions in time and thus maximising efficiency through the reduction of waste. Though all these systems started in the manufacturing industry, the concept of 'production process' can readily be applied to any other set of processes, even those that do not produce physical products. Consequently, lean manufacturing has been greatly influential as a way of thinking in many industries beyond its automotive roots (Hines, Holwe et al. 2004).

The TPS focused on pinpointing and eliminating waste (Womack, Jones et al. 1991; Abdulmalek and Rajgopal 2007). A series of tools were developed to help map and consequently eliminate three areas. These were: 'Muda', also known as the seven wastes, 'Muri' known as the overburdening of people or equipment, and 'Mura' the unevenness or irregular production (Womack and Jones 1996; Hines and Rich 1997; Hicks 2007). The categories developed to describe the seven primary wastes (Muda), plus the eighth waste of underutilisation of people added later in development, are shown in Figure 2

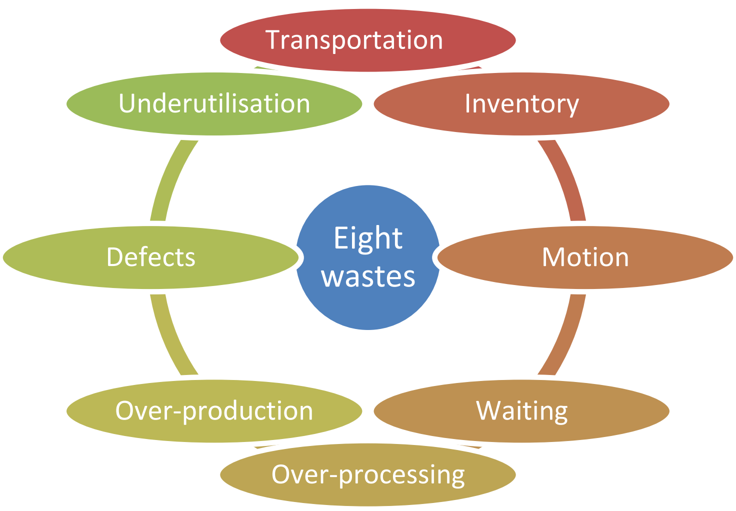


Figure 2: The eight wastes to be eliminated in a lean manufacturing system.

The lean methodology also subsumes many of the ideas from total quality systems, particularly the problem-solving approach. This may be summarised as investigating a problem > identification of the impediments > application of an improvement process > ongoing cycles of continuous improvement. The concept of empowerment of operators to make suggestions and arrange their own work is also common. Indeed both quality and lean are reliant on a culture that welcomes operator engagement in the production processes beyond merely the provision of labour. The burst of activity that creates the incremental improvement is a kaizen[10] activity. In this context the term means that good is never good enough and that no process can ever be thought to be perfect. So therefore each process must be continually evolved and improved.

The lean production paradigm can be accomplished by applying a wide variety of lean manufacturing tools such as Heijunka, Six Sigma, Kanbans, First In-First Out (FIFO), Value Stream Mapping (VSM), Takt (from Taktzeit meaning cycle) time, Just In Time (JIT), Single Minute Dye Exchange (SMDE), and 5 S principles (Abdulmalek and Rajgopal 2007).

There have been many attempts to explore the effectiveness of different techniques used to implement lean thinking in a real practice along with examining why some techniques might be preferential to others (Lasa, de Castro et al. 2009). The tools themselves are a vital component of lean implementation along with the defining culture of lean.

2.2 Value Stream Mapping

VSM is a functional method or visual flow chart by which the production process can be represented as a set of processes connected in time. The method excels at showing the time dimension, particularly the non-value-added (NVA) or wasted time. It is therefore the lean method of choice for industries where costs are mostly determined by time, or where a shorter production cycle provides a competitive advantage. VSM can map an entire process, supply chain network, or the sub-tasks within a single process. It therefore readily scales hierarchically. In addition it maps both material flow and the information that controls production (Braglia, Carmignani et al. 2006). The method, being a type of flow chart, is typically implemented using a set of standard icons for information and material flow (Womack and Jones 1996; Rother and Shook 1999; Tapping, Luyster et al. 2002; Lian and Van Landeghem 2007).

A given value stream includes all activities that contributed to a product, i.e. value adding, non-value adding and supporting activities that are required to render the service (Seth and Gupta 2005; Kuhlang, Edtmayr et al. 2011;

[10] *Kaizen refers to the lean philosophy that no process can ever be perfect, so operations must be improved continuously through waste elimination events*

Singh, Garg et al. 2011). The concept of waste within a manufacturing or information system can be further expanded through a categorisation of NVA work, Necessary but non-value adding (NNVA) work and finally value added (VA) work (Monden 1993; Womack and Jones 1996). Using these principles, the baseline processes within the value stream can be established and categorised. Once the value stream has been mapped, it becomes the baseline for improvement. This can be used to help create a future state map, which represents the desired future state including process improvements and reduction of NVA and NVA waste.

VSM is widely recognised in many different organisations irrespective of the type of system under examination. Research has mostly been focused on push/pull, Kanbans, inventory control and mixed model assembly implementation. There has been less research into adapting concepts such as JIT, continuous improvement, cycle time reduction, visual management, automation, and floor space reduction into VSM simulation (Gurumurthy and Kodali 2011). Another commonly recognised flaw in VSM is the inability to map value streams other than cycle time or cost. A limited number of modified VSM concepts have been developed to cope with complex value streams primarily network value mapping and critical path VSM.

2.3 Strengths of VSM

Some of the primary strengths of VSM are (Lasa, de Castro et al. 2009; Gurumurthy and Kodali 2011):

- VSMs are able to easily identify waste (time & cost) from the values stream
- VSMs allow organisations to guide and visualise future information and material flow with iterative process improvements
- Maps more than just waste; allows source and root cause to be examined
- Provides simple and objective analysis of complex systems.

2.4 Limitations of VSM

As with the all processes, VSM has associated weaknesses inherent within the system design that limit the ability of VSM to be applied in every circumstance. A variety of the limitations inherent in VSM are described below (Irani 2004; Lasa, de Castro et al. 2009; Gurumurthy and Kodali 2011; Singh, Garg et al. 2011).

- Static tool that captures snapshot-in-time not continuous flow
- Future state assumes every Kaizen will be fully completed
- Editing VSMs drawn by hand is cumbersome
- Detail capture of value stream is limited, especially in more complex multi-stream systems
- VSM doesn’t represent spatial layout and consequent impacts of distance.

2.5 Methods of environmental waste management

Waste management is the processing, collection and transportation of waste[11] to recover residual value or reduce consequences for the natural environment. Arguably the most widely used and universal waste management focused system is the ISO 14000 which is a family of standards relating to environmental waste management (ISO:14031 2000; EPA 2011). They assist an organisation in minimising how their operations or processes can negatively affect the environment (i.e. cause adverse changes to air, water, or land). The ISO 14031 standard (from the ISO family) relates to Environmental Performance Evaluation (EPE) and is a management system which aims to assist organisations in identifying their environmental impacts by determining which aspects they will treat as significant, setting criteria for environmental performance and assessing its environmental performance against these criteria. As part of the IS0 14000 family, another approach is found within the ISO 14040 set of standards, described as the Environmental Management – Life Cycle Assessment – Principles and Framework. The principal definition of the "Life Cycle Assessment" (LCA) is the assemblage and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout the product's life cycle. The LCA model is a more focused approach to waste management than ISO14031.

Cradle to cradle (C2C) is a methodology that uses biomimicry to compare and analyse the human resource system as a biological organism where materials and resources are modelled as nutrients in a health metabolism. The initial coining of the term was by Walter R. Stahel in the 1970's, but it wasn't until a modification of the Life Cycle Assessment saw the birth of the C2C ideology through the publication of *Cradle to Cradle: Remaking the Way We Make Things* (McDonough and Braungart 2002). The primary theory of the C2C principle is the idea of regenerative design in which every product is produced in a way in which it ensures recyclability of the resource.

The polluter pays principle (PPP), also known as extended producer responsibility (EPR), emphaises that the summation of all environmental costs throughout the lifecycle of any product should be reflected in the market price of that product. PPP aims to change the waste paradigm from a governmental focus on waste and environmental initiatives. The shift is to corporate or manufacturing entities which produce the waste and thus should also deal with waste impacts and disposal. This would mean that manufacturers would absorb greater responsibility in the cleaning, storing, recyling and reuse of waste produced. This type of thinking has increasingly affected national policy formulation. Therefore, it is becoming increasingly important for manufacturers to devleop systems to better manage their environmental waste. The preferential method of waste management would be prevention and minimisation of waste at point-of-generation, as opposed to disposal and energy recovery. Hence the desirablity of including environmental waste into lean thinking.

2.6 Waste management indices

[11] Defined as: "non-wanted things, that are perceived to have no purpose or value".

Once an overall waste management framework is determined, it is crucial to then decide on an appropriate index in which specific environmental performance factors can be evaluated against. There exists several methods in which the environmental consequences can be measured or evaluated directly. It should be noted that a majority of the indices do not directly account for the principles of a lean manufacturing programme. The ISO 14031 standards highlight the development of specific metrics through indicators. The process of choosing the indicator may include choosing from existing indicators or developing new indicators[12].

The US Environmental Protection Agency (EPA) (EPA 2011) environmental toolkit provides assistance in developing an environmentally conscious organisation. The most relevant features of the EPA toolkit relate to identification of environmental wastes and an Environmental Value Stream Mapping (EVSM) adaptation. This discussion is primarily interested in the identification of wastes. Initially the toolkit describes links between the 'seven wastes' and environmental wastes in identifying critical environmental impacts. The EPA toolkit further explores the ability of targeting environmental waste in an organisation.

Environmental Management Accounting (EMA)[13] is a combined process that provides a method to translate data from financial accounting, cost accounting and mass balance to improve material efficiency and reduce environmental impacts (Jasch 2003). The primary focus of EMA is an assessment of the total annual environmental expenditure on emissions' treatment, disposal, environmental protection and management. In essence EMA sets up procedures for internal decision-making which include both physical procedures for material and energy consumption, flows and final disposal, and monetarized procedures for costs, savings and revenues related to activities with a potential environmental impact.

The total emissions method seeks to determine (through empirical analysis) evidence of a link between lean production practices and environmental performance (King and Lenox 2001). The method explores three interrelated hypotheses. The hypotheses state: (1) that the more an organisation establishes lean principles, the more likely it will adopt formal environmental management systems, (2) the less likely it will generate waste and (3) finally, the lower its emissions will be. In other words, an organisation's environmental performance could be defined by the degree it emits toxic pollutants (Hart and Ahuja 1995).

Several other systems attempt to quantify environmental data. The systematic (or strategic) environmental assessment (SEA) incorporates environmental considerations into policies, plans, programmes and strategies of

[12] This standard describes the two general categories for Environmental Performance Evaluation (EPE) as: Environmental Performance Indicators (EPI) or Environmental Condition Indicators (ECI). EPI can be further broken down into Management Performance Indicators (MPI) and Operation Performance Indicators (OPI). MPI are a type of EPI that provide information about management's efforts to influence the overall environmental performance of the organisation. On the other hand, OPI provides information about the environmental performance of an organisation's operations. Examples of how these three indicators inter-relate are given in ISO 14031:2000.

[13] As described by United Nations Division for Sustainable Development UNDSD 2001.

an organisation (Brinkley, Karlsson et al. 2000; Salhofer, Wassermann et al. 2007). Life cycle assessment (LCA) is a core concept in the development of environmentally-conscious design and cleaner practices in industry and involves the evaluation of environmental burdens associated with product, process, service or practice. Volvo along with the Federation of Swedish Industries jointly developed an Environmental Priorities Strategies (EPS) system to select appropriate materials to use during construction of its products (Hokerby 1993; Richards 1994). This method is based on environmental indices calculated for specific materials.

Another possible cumulative measurement for wastes is the use of a ‘carbon footprint’ analysis in which waste of a very specific form can be aggregated and measured. The ‘carbon footprint’ analysis is a method in which the total emissions of greenhouse gasses (GHG) are estimated in terms of the carbon equivalence (tCO_2e-tonnes of carbon dioxide equivalent or grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh)) from a specific product. The measurement is taken across a product’s life cycle from raw materials used in manufacturing to the disposal of the final product. Its purpose is to measure the individual gas emissions from each activity within a supply chain process and framework and attribute these to each output product (Wiedmann and Minx 2008). A carbon footprint, in other words, is a measure of the total amount of greenhouse gas (GHG) emissions. Carbon dioxide, methane, nitrous oxide, hydoflurocarbons, petroflurocarbons, sulphur hexafluoride, ozone are examples. These GHG emissions are either directly or indirectly caused by an activity or are accumulated over the life stages of a product.

Toxicity was another possible measure of environmental impact, particularly the impact of a set process with respect to human health. Initial investigation of the use of toxicity as a potential environmental impact factor (EIF), particularly LD_{50}, was discarded due to the high degree in variability of data available for any substance measured. High use of estimated data along with large uncertainties and safety factors did not promote the use of this particular EIF as a contribution to the creation of an Environmental Impact Index (EII).

The Global Report Initiative (GRI 2006) promotes economic, environmental and social sustainability. GRI provides companies and organisations with a sustainability reporting framework. The framework includes identification of a variety of aspects oriented towards long term sustainability for the often described economic, environmental, and social categories. Within the environmental dimension is a section with a number of aspects concerning emissions, effluents, and waste with both core and additional performance described. Other performance indicators of the GRI (Environment) include the aspects of: materials, energy, water and biodiversity making a total of 30 performance indicators. The GRI has become a widely used methodology for companies to measure and report on their sustainability practices with specific measurements identified.

3.0 Purpose: A need to integrate environmental factors with lean

Current concepts of environmental waste focus on the total production of waste from a plant. They are interested in quantifying the amount of waste and its consequences on the natural environment. Hence an emphasis on containing waste within the plant boundaries and applying post-production processes to eliminate or minimise the impact following the waste hierarchy.

There is a growing awareness of the importance of incorporating environmental factors into lean methods. There have been a number of initiatives in this direction. Integrated Definition for Function Modelling (IDEF0) is one method used as a modelling notation to incorporate an existing waste index (Patil 2002). That work at least showed that it was conceptual possible, but did not implement environmental factors into operational practices in the real industrial setting. The United States Environmental Protection Agency (EPA) has developed an environmental value stream map (EVSM) method which examines natural resource flow by expanding the mapping process to include environmental waste streams (EPA 2011). This method has been applied to reduce water consumption in an alcohol and sugar industry case study (Torres and Gati 2009). This method easily focuses on one particular form of waste but lacks the ability to focus on environmental waste as a whole or even multiple environmental waste streams.

However, clean environmental identification practices will also require reduction of waste at its point of generation. Waste is generally not generated by a plant in total, but by individual processes within the production. Therefore focussed management of environmental waste requires that production engineers first know what the waste is, and where it is being generated. This is the crux of the problem, because this is often simply not known with any accuracy. In addition, production plants are controlled and improved by lean methods. If some waste is not visible to the lean methods, then it will not be included in the continuous improvement cycles. It is therefore imperative to identify and embed the environmental issues into the lean tools.

There have been only minor developments in creating an overall value stream environmental index and an encompassing methodology. What is needed is a way to include environmental waste alongside the other lean wastes. If this can be achieved, then the organisational momentum and culture that sustains the lean initiatives will automatically ensure that environmental waste is included in the decision-making process.

4.0 Approach taken

This project was contextualised in a research collaboration with a local industry partner. This firm provides remanufacture services for a high-value precision engineering product. The firm already had an established process for implementing VSM. What was missing was the incorporation of the environmental impact of each process. This was important for the firm for two major: first, that the processes can involve toxic materials and secondly that the reduction of environmental waste was seen as a strategic competitive advantage.

We approached this problem in the following way. First, we created a composite environmental waste index. We used a variety of environmental impact factors, which were then integrated to form a single new impact index that was relevant to the operational purpose of the firm. We created several different concepts for how such an index might be visually represented within the VSM framework.

Second, we tested the relevance of these concepts within the firm. Focus groups within the industry were used to identify the waste-types and index factors that were most applicable to the situation. They also selected, from among the multiple concepts, which visual representation was best for them. The focus group comprised of several people from a variety of roles within the firm, including engineering managers, Environment Health and Safety officers and quality control engineers. This part of the method ensures that the results are relevant to the industrial perspective, and provides a degree of confidence in the applicability. We did this from awareness that adoption within an organisational culture is important for the success of any new initiative, hence the special care to engage stakeholders in the design process.

Third, from the results of the focus group, we then designed the details of an integrated environmental waste-VSM (EW-VSM) method. We shaped this around VSM as that is the dominant lean tool used in this type of industry. We found a way to represent multiple dimensions of environmental waste (in this case five) for each process in the value stream. We also found a way to represent the aggregated environmental waste for the whole value stream. This permits the methodology to scale with the production hierarchy.

The fourth part of our method was to deploy this EW-VSM in the firm, on actual production lines. An environmental value stream mapping exercise was conducted on a process that was identified to incorporate a large amount of environmental impacts (such as high energy use, carbon footprint, high cost of waste removal and toxic materials). A current state map of the process was constructed by a team including a quality engineer, VSM specialist, production workers, and technical manager. This exercise was conducted over a three day period. The implementation began with a tutorial of how the environmental impact analysis methodology worked and how it was integrated with VSM use. The selected practitioners were informed of the new methodology through the use of standard operating procedures (SOP) that had been specially written describing the new environmental impact index.

The implementation continued after informing the users about the concept, the index implementation and evaluation. The evaluation started with a review of a particular process (Annulus Filler). Once all participants were informed of the overall approach of the environmental index method and its relationship to VSM, the first stage of the analysis was instigated. The data acquisition begin with setting the initial percent target waste reduction (in this application 80% was chosen) followed by the capture of all five impact factor components. The data capture included calculation of all carbon footprint data by hand, perceived impact, determining cost to remove waste, volume of waste removed and remaining and finally the site based Risk Register values for each process. The environmental impact factors were then aggregated into the single environmental impact index for each of the nine stages of the VSM. The VSM (with added environmental impact index data bar and summary system radar chart) was then analysed along with the process radar charts to determine which process had the highest environmental impact. Finally, after all information was captured as required, the environmental value stream ladder was added to the VSM, as well as Kaizen events identified.

The fifth and final part of our approach was to seek feedback from the users for their responses to the method. We did this by a survey. We were interested in the relevance and ease-of-use from the perspective of industry practitioners. This part of the method was therefore a check on the applicability of the EW-VSM construct. The survey questions are included in the results. The respondents were from those who had participated in the EW-VSM, as well as other key roles within the plant. Ethics approval was obtained for the survey from the University of Canterbury.

5.0 Results

5.1 Environmental Impact Index (EII)

Several factors relating to the use of an index at the local industry based sponsor were required to be taken into consideration when developing the appropriate aggregated composite EII scale. The first key factor for aggregated scales is the need for an index that can consider the broader definitions of waste and environmental impact, and accommodate the specific operational characteristics and strategic purposes of the organisation. A design with a multi-levelled weighting scale can accommodate a wide variety of environmental impact factors.

A series of nine possible environmental waste impact indices were initially examined. The EPA toolkit, EMA method, Emissions index, SEA index and ISO14000 were all been omitted at this stage of the project due to several limitations. Of these, the EPA toolkit, EMA method and ISO 14000 were eliminated due to their low scores for ease of use, ease of integration and adaptability. The Emissions and SEA index suffered from being too specific and inflexible in accommodating different forms of waste or environmental impact scenarios.

The possible candidate indices were an adapted Volvo environmental priority system, simple carbon footprint index, GRI index, simplified risk and consequence index, and a custom scale. Benefits of these indices included:

- ability for some indices to accommodate multiple environmental factors (Custom scale)
- some proposed indices were widely used and recognized (GRI and ISO)
- ability to adapt the index was recognized as a key benefit (Custom scale)
- ability to quickly and effectively reflect poor performing processes
- ability for practitioners of various skill levels to use and operate.

Detriments of these selected indices include:

- some indices were based on single environmental factors (Volvo and carbon footprint)
- some indices (including custom scale) were not recognized or officially vetted
- overly complex index creation (GRI and ISO) was ruled out.

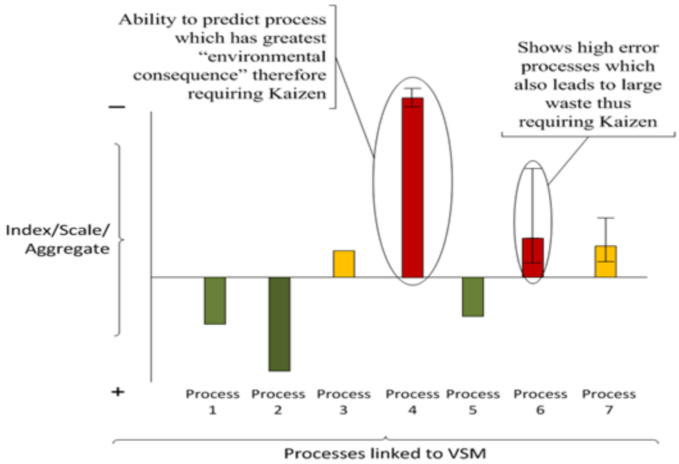
5.2 Conceptual design of an index for environmental waste

We applied a conceptual design process to the development of the Environmental Impact Index (EII) and its visual representation. We did this because representation is an important factor in usability and we were specifically interested in a scale design that would be easy to implement. Thus, we were also designing for change-management. For this reason the process of design specifically included focus groups from within the industry under examination.

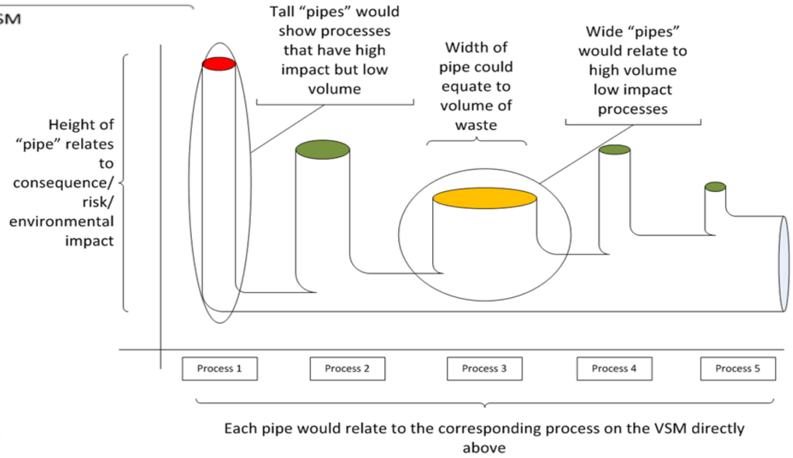
The study examined possible visual displays to represent the chosen index. We also needed the representation to be easily integrated into current VSM maps. To consolidate the disparity gap between overall site waste data and process level information, two main design criteria were required to be met. The first element required to consolidate the disparity, was to create or modify an appropriate waste index and encompass this index into an overall evaluation methodology that could be used to determine specific environmental impacts at the process level. The second criteria required to be fulfilled was to create a robust visual representation method that would effectively highlight high environmental impact processes that required Kaizen (waste reduction) initiates.

Several concepts were explored through focus group review sessions. These concepts included a bar graph display, representative symbols, and simple process flow charts, shown in Figure 3. Participants selected a coloured flow process chart, for clarity of communication and ease of integration with VSMs. The summary of the EII was then displayed as an environmental waste impact ladder below the current lead time ladder as shown in Figure 3.

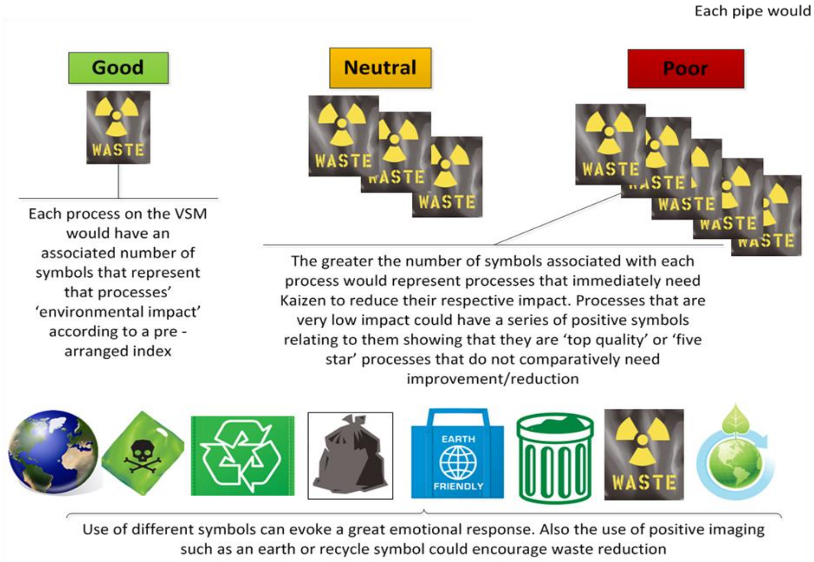
Bar graph concept



Waste pipe concept



Symbolic representation concept



Process chart concept

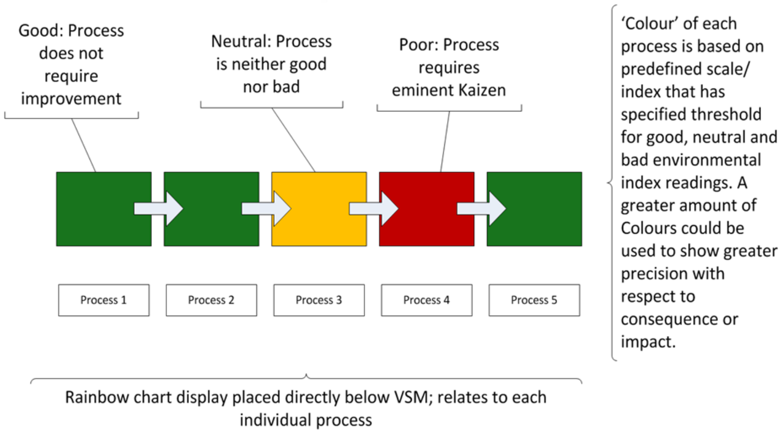


Figure 3: Summary of initial visual display concepts.

Following further industrial practitioner based focus-group review sessions with leaders in the Environment Health and Safety (EH&S), lean and VSM (Value stream mapping) groups, a final customised index was chosen which incorporated various aspects of the previously described standards and indices. The most favourable index by general consensus was a customizable index that would allow the organisation to modify the index based on current site objectives and organisational purpose. A custom scale was also deemed the most preferred option because it allowed a balance to be created between accuracy of results, adjustability of index and adaptability of the applied method to highlight high environmental waste impact process. An important specification identified by the focus group was to develop a composite index to be customisable to allow for future modifications as a result of changes to the organisational purpose of site goals, essentially future proofing the methodology and index. Five EIF were chosen, reflecting the current strategic goals and organisational purpose of the particular industrial application. Descriptions of the chosen set of EIF for this application were:

- carbon footprint
- perceived impact of waste [levels 1- 10]:
    - **Level 1:** Relates to near zero or minimal perceived human impact such as paper or storm.
    - **Level 5:** relates to medium level of perceived human impact such as sewage.
    - **Level 10:** relates to very high perceived human impact such as anthrax, radiation or asbestos.
- cost of cleanup/remediation per kg
- removed waste volume x Site Environmental Risk Register value (Based on ISO14001 standards)
- remaining waste volume x Site Environmental Risk Register value (Based on ISO14001 standards)

These cover all the factors that the focus group deemed pertinent to the site. However we noted that the method was able to accommodate different factors and different numbers thereof. Thus we recommend that practitioners give thought to the wastes appropriate in their own situation rather than unthinkingly adopting the above list.

5.3 Creation of composite index for environmental waste

Creating a composite index consists of several key stages: the initial EIF estimation, determination of an average EIF, and aggregation of the final EII (this overall process is shown in Section 5.3). The aggregation of the composite index starts with the definition of the chosen environmental impact factors (EIF) shown in Figure 4. These interchangeable factors are the foundation for which the final EII will be based on, and must be selected carefully to reflect the organisational purpose, goals, and environmental aims of the organisation in question. The chosen factors used in this particular application were decided through a series or focus group discussion as discussed previously.

Percent contribution of process EIF to total EIF

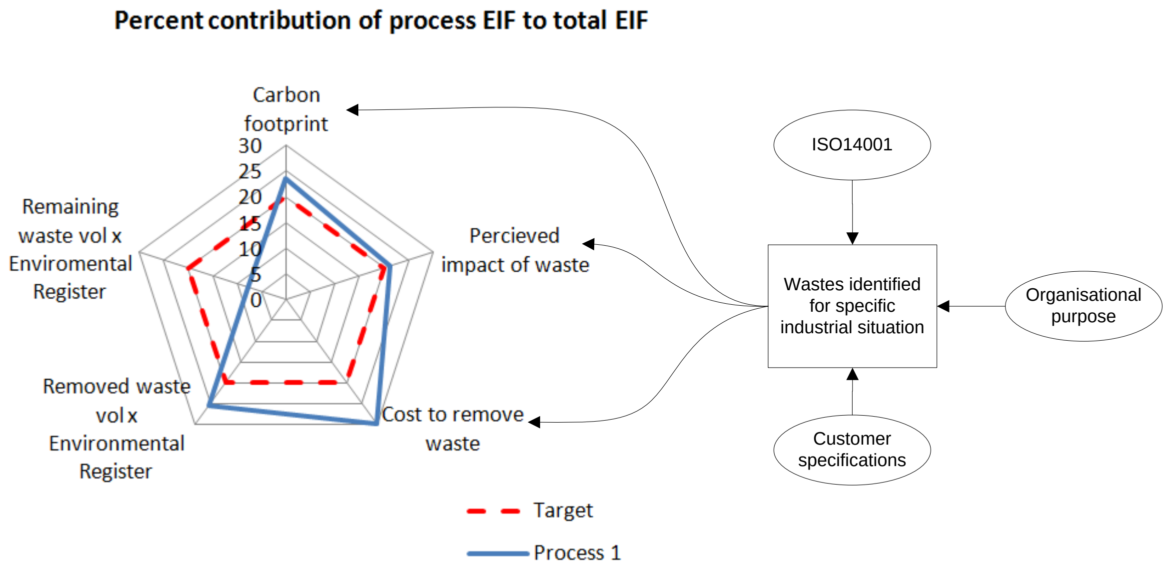


Figure 4 Initial environmental impact factors chosen and subsequent radar chart for Process No 1 in the value stream.

The second aspect that must be defined is the scaling factor (SF). This element allows a layered system approach to be undertaken when determining which EIF is most important from a customer, practitioner, or manufacturing perspective. This pre-weighting also allows compensations to be made for low numerical valued EIF. At the outset, the SF would remain 'one' unless a specific EIF needs to be highlighted or targeted. If a larger SF is required, the practitioners can increase the SF in increments of 10 until a suitable value is reached. This reduces the complexity of determining an appropriate number. This SF is used as an alignment modification factor to reduce or enlarge the importance of any of the chosen EIF. This might be useful to reflect a changing organisational strategic purpose, for example placing greater importance on say carbon footprint. By increasing the SF of the carbon footprint aspect, the company would effectively increase the percent contribution of that EIF to the overall index. Importantly the production improvement processes inherent in the lean system would automatically refocus to reduce this particular waste.

Once the appropriate EIF is confirmed, the data collection for each EIF begins. To compensate for inaccurate, limited or estimated data collection of an EIF, a project evaluation and review technique (PERT) analysis was used to determine an average EIF value. This proceeds from fitting a beta probability distribution to three estimates, is shown by

and Figure 5. The EIF values are separated into Pessimistic (P), Expected (E) and Optimistic (O) values. The distribution is weighted towards the expected EIF value, as per the function for the mean of the beta distribution. This also minimises extreme data outliers such as an overly optimistic or pessimistic evaluation.

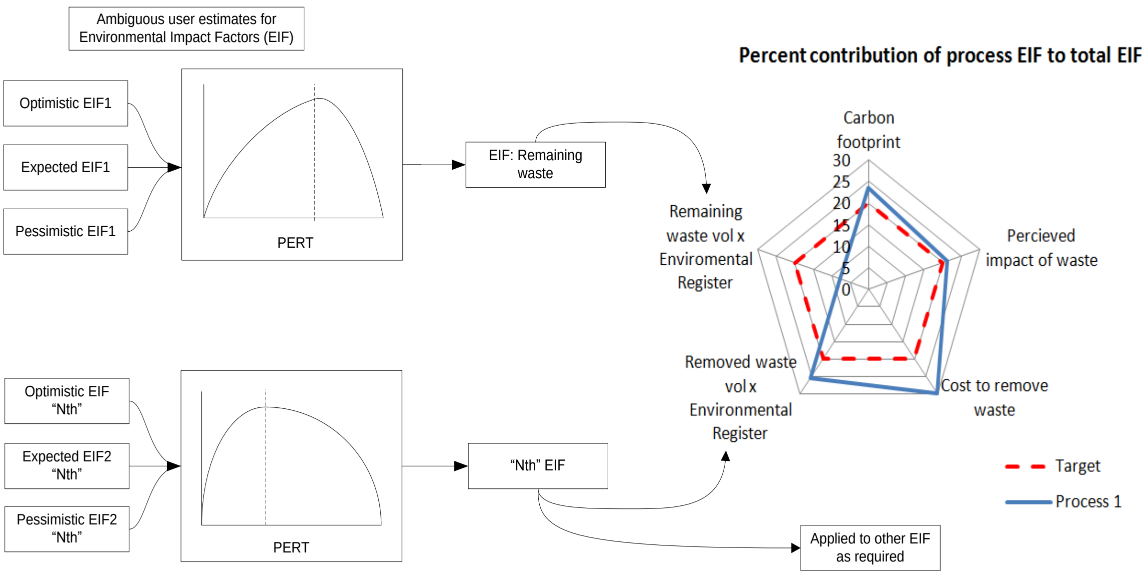


Figure 5: Method of determination for each environmental impact factor value using the PERT three point estimation.

Equation 1 $$EIF\ estimated\ =\ (O + 4E + P)/6$$

After the mean EIF value is determined, the EIF is then multiplied by a scaling factor (SF), as determined above. The next stage of the aggregated composite index is to assimilate the various EIF into a single index. This is determined by adding the vector magnitude of each EIF together, shown in equation 2.

Equation 2 $$EII\ (vector\ magnitude) = \sqrt{(EIF_1 * SF_1) + (EIF_2 * SF_2) + \cdots + (EIF_n * SF_n)}$$

There are several reasons for using a vector magnitude to determine the final EII. The first is that this permits any number of waste dimensions to be consolidated to a single value, i.e. it makes the method scalable. A representation of a 3 dimensional waste problem is shown in Figure 6. Although a graphic representation is unavailable for the general nth dimensional problem, the vector magnitude still works.

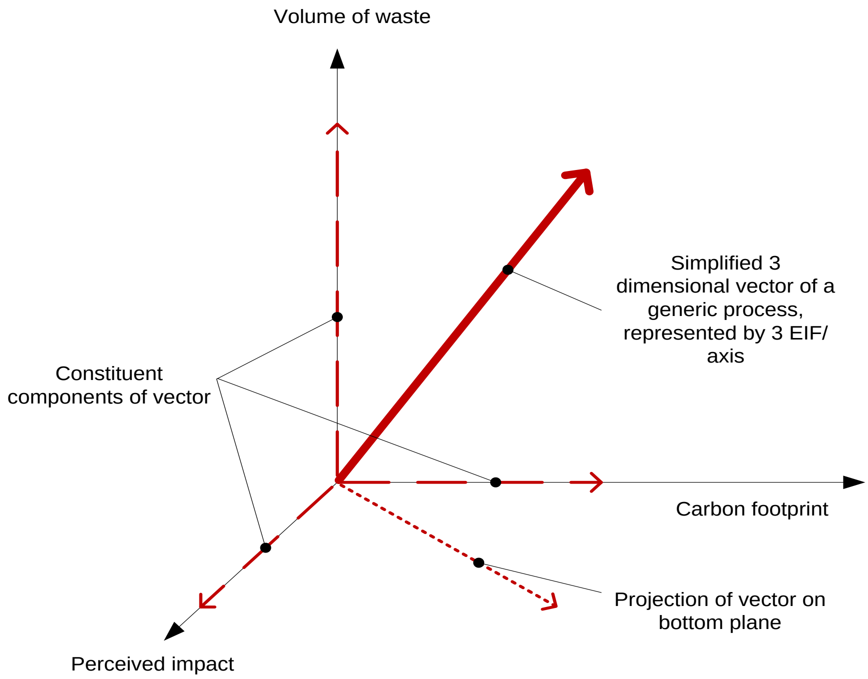


Figure 6: Simplified three dimensional vector representation of generic system process[14]

The second reason for using a vector magnitude relates to the inability to simply multiply or add the EIF together. Direct multiplication or addition of the chosen EIF is not recommended, as this could often result in large number-valued solutions for specific processes as a result of one particularly high EIF that could skew the results. This problem is solved by using the vector magnitude equation, as well as incorporating a scaling factor in the magnitude equation to ensure no single EIF or process dominates the overall analysis. Thirdly, the vector magnitude approach allows for the likely event of a specific process having a zero valued EIF. If multiplication was used, then the final value representing a process with a zero valued EIF would be reduced to zero, reflecting

[14] This reason relates to the theoretical modelling used to address the problem and create a suitable solution. The approach used was to examine if the application of risk maps and consequence scales, representing environmental risk, could be used to provide a single valued solution. This concept of a risk map was replaced by a model in which the x and y axis described EIF characteristic of carbon footprint and volume of waste for a specific process. This model was further expanded to include a greater number of axes that represented different appropriate EIF. The end result was the creation of an nth dimensional model that could be used to describe any number of EIF. Finally a five dimensional model was chosen, with each EIF being represented by a separate axis. Each process could then be mapped in accordance to the contribution of EIF, represented by a separate axis. This resulted in a representative 5 dimensional vector for each process, shown by a simplified illustration in Figure 6. The vectors describing each process could then be consolidated into a single valued unit through the use of the vector magnitude equation. This also means that with the addition of any extra 'dimensions' describing a different EIF, the final solution can be easily adjusted by adding in another vector component.

an inaccurate result. The vector approach allows for any number of EIF to be zero values and still results in a final indicative EII.

Finally, addition of EIF was considered a possible aggregation method. However due to both large number dominance of some EIF compared to others, as well as unit mismatch, this was discarded in favour of the vector approach. The methodology created is able to accommodate any number of types of waste, as discussed above, and we refer to this as an n^{th} dimensional concept. The current model uses 5 waste dimensions. Each of these is represented on one axis, and additional axes may be added and further wastes are included. The vector magnitude then reduces the nth dimensional representation to a single value. This is useful for the ability to report summary data to managers and corporate staff, and hence indicate how well the plant is meeting the strategic objectives. Thus, the method integrates well with strategic management initiatives at the one level, and lean improvement (via VSM specifically) at the operational level.

5.4 Identifying environmental Kaizen opportunities for improvement

The purpose of lean initiatives is to identify areas for continuous improvement. These improvement foci are termed Kaizen events. Also important in lean processes is the realisation that not everything can be improved because of finite resources. It is therefore important to be able to identify which deficiencies are most worth targeting. In the case of value stream mapping, it is usual to use a burst symbol to represent the Kaizen events on the VSM chart. Also, VSM uses the concept of future state to identify the target reduction in non-value-adding times. In the case of the environmental VSM approach described here, the Kaizen concept is directly applicable. It is straightforward to identify where to apply the environmental Kaizen, based on the process activities with the highest waste scores. Contextual knowledge of the plant may then be used to further identify which processes are likely to be more or less amenable to change. Note that the environmental Kaizen are not necessarily at the same location as those for the standard VSM. This is because the one set of process improvements are focussed on the environmental issues, and the other on the temporal. (We use a green burst symbol to show the environmental Kaizen and yellow for the temporal.)

In application, the selected environmental impacts are integrated into a single EII, and a series of radar charts created. These display the performance of individual processes and the overall system. Radar charts and conditional formatting are then used to identify the processes which required environmental Kaizen initiatives. The first set of radar charts used are at the process level and they break down each individual processes performance compared to an overall threshold value as shown in Figure 7. This threshold may be determined by creating an overall 'target' percent based value of the maximum calculated index. The highest index would be multiplied by the high and low percent targets. These percents are then used across the entire system to determine good, neutral and bad performing processes.

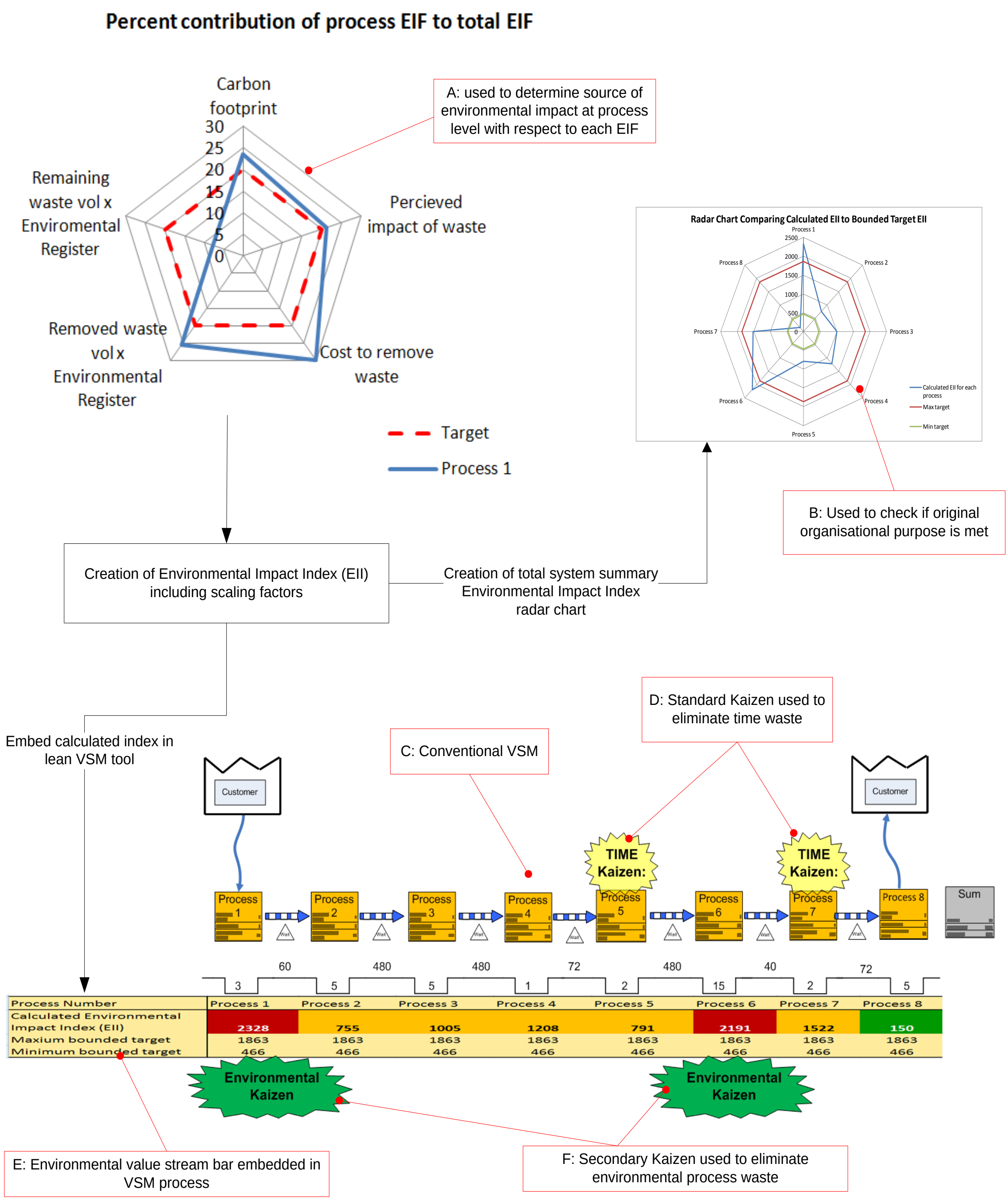


Figure 7: Illustration displaying the method in which final EII is aggregated from EIF data (A and B), the conventional time value stream (C and D), how the environmental impact index is incorporated into VSM (E) and the resulting environmental Kaizen created (F).

The radar charts are used in two ways. The first radar chart (B in Figure 7) is a summary figure which displays overall process performance of each process compared to the percent thresholds. The high percent threshold is determined by reducing the highest calculated EII by the top percent target, whilst the low threshold level is determined by multiplying the highest calculated EII by the low threshold bounded percent target. Any process above the maximum threshold in the summary radar chart can be described as a critical process requiring

Kaizen activities to reduce the overall EII value. Conditional formatting has been used to set the displayed summary process environmental impact index to red to reflect a poor EII performance if above the maximum threshold. Processes that are between the bounds are ones that do not require immediate attention, but have the potential to have a large EII over the next few EVSM iterations. They are set to display yellow. Finally, processes below the minimum threshold are set to a green showing that they will most likely not require intervention.

The second use of the radar chart is to display a breakdown of each processes performance with respect to the chosen EIF. The first step is to determine the total sum of the total system EIFs. Each process radar chart is then created by determining the percent contribution of that processes EIF to the total system EIF. The practitioner can easily compare and identify which environmental factor of what particular process requires Kaizen implementation (as shown in Figure 8). The final aspect of the index incorporation is the inclusion and transfer of the summary EII data onto the standard VSM templates creating the final EVSM product. An example representative EVSM is shown in Figure 7). The figure shows a representative standard value stream (yellow data boxes), standard "time" domain Kaizen and the associated lead time ladder. Below the lead time ladder is the main contribution of this system—the inclusion of an integrated environmental impact ladder and associated environmental Kaizen linking key lean VSM use with environmental considerations.

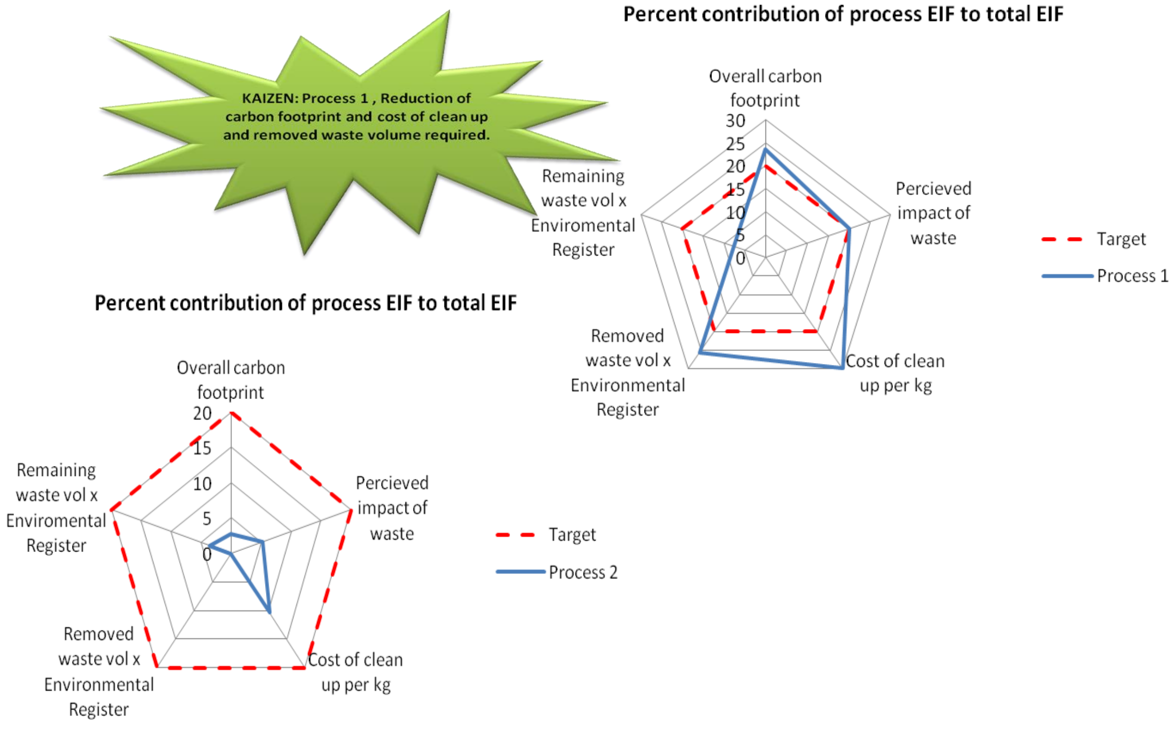


Figure 8: Representative sample and comparison of two process EIF radar charts and example of Kaizen for high environmental impact process one.

5.5 Application to industrial case study

The industrial case study under examination is an organisation that remanufactures aviation turbines. Quality of work is of utmost importance, due to the safety and reliability considerations. In addition, a rapid turnaround of the product is important for the client's utilisation of expensive airframes. The minimisation of environmental waste is important both for the client (the aviation industry is sensitive to carbon footprint) and the remanufacturer (toxicity of plating processes in particular). The environmental VSM approach was applied in this environment and the results follow.

First, the firm identified the EIF to which it was sensitive (see 5.1 above). These were carbon footprint, perceived impact of waste, cost of cleanup/remediation, removed waste volume (weighted according to Site Environmental Risk Register), and remaining waste volume (likewise weighted). This made for a total of five impacts however, the methodology accepts any number. The environmental impacts were then assessed as part of a real VSM development.

5.5.1 Current state environmental VSM

The EVSM method described was applied to a production process value stream within the industrial setting. A typical process stream might consist of between seven and a hundred activities depending on the level of detail required for analysis. The chosen value stream consisted of nine process stages that contained a large variety of environmental waste impacts. The method was applied to the VSM chosen and the EVSM created, as shown by Figure 9.

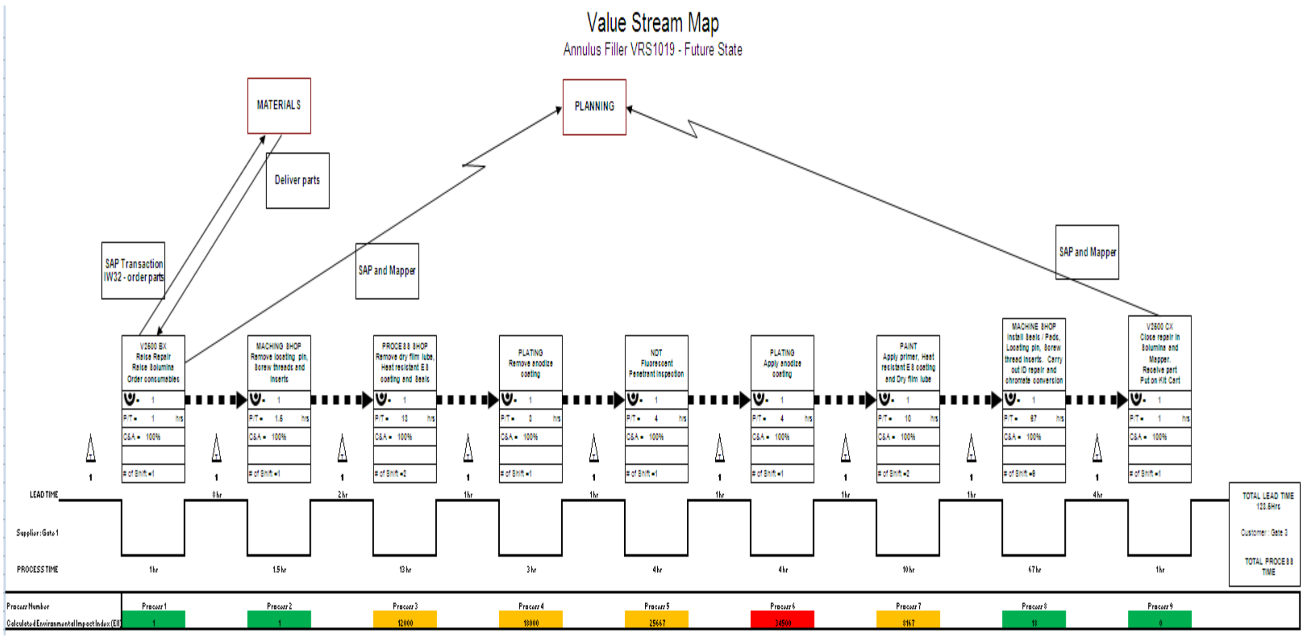


Figure 9: Implemented Environmental Impact Index incorporated with VSM for the chosen industrial value stream.

5.5.2 Environmental Kaizen

This process resulted in a key Kaizen being created for the high environmental impact process six, as shown in Figure 10.

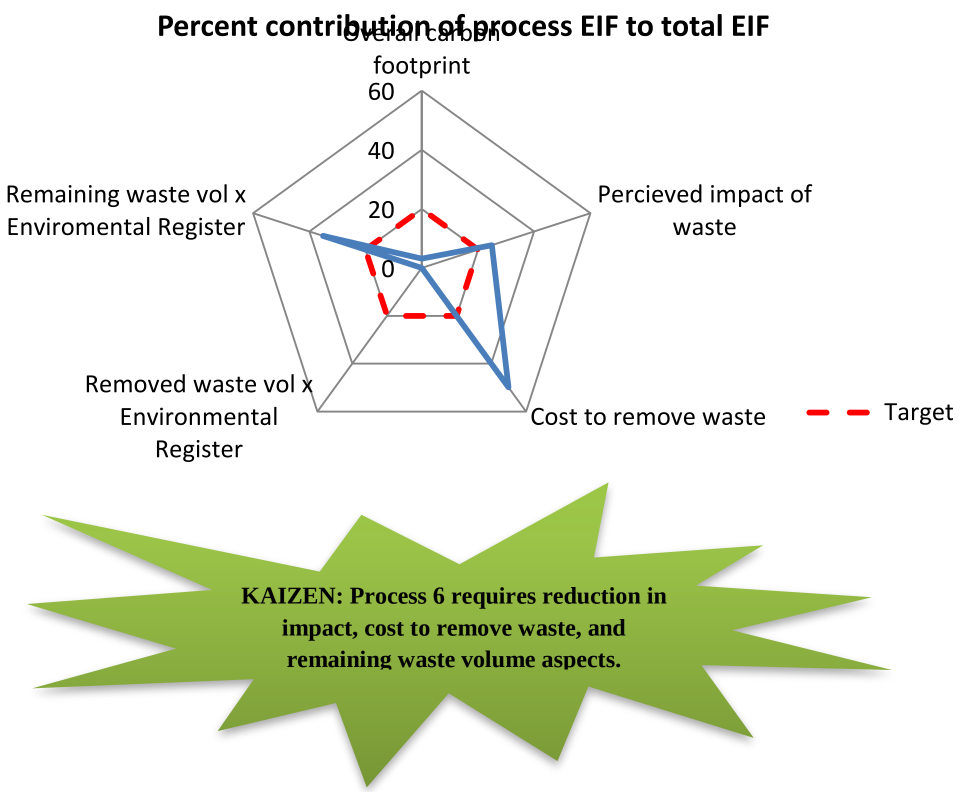


Figure 10: Process level radar chart providing key output - environmental Kaizen created in response to high impact process and waste identification through use of applied method and radar charts (i.e. Process 6 – Plating: Apply anodize coating).

There is always a balance between economic and environmental goals during the continuous improvement process and for this reason it is useful to have managerial representation in the Kaizen event. In principle, the target future environmental waste levels can be included on the future state map.

5.6 User survey of applicability

To validate the effectiveness of the created EVSM method and associated index, a survey was conducted of industry participants. The questions relevant to the present study were:

- Question 1: To what extent is it important to measure environmental waste impacts?
- Question 3: To what extent does the practitioner feel the tool was successful in promoting new thinking and continuous improvement?
- Question 4: To what extent does the practitioner feel the method was effective at identifying environmental waste impacts?

Responses are shown in Figure 11.

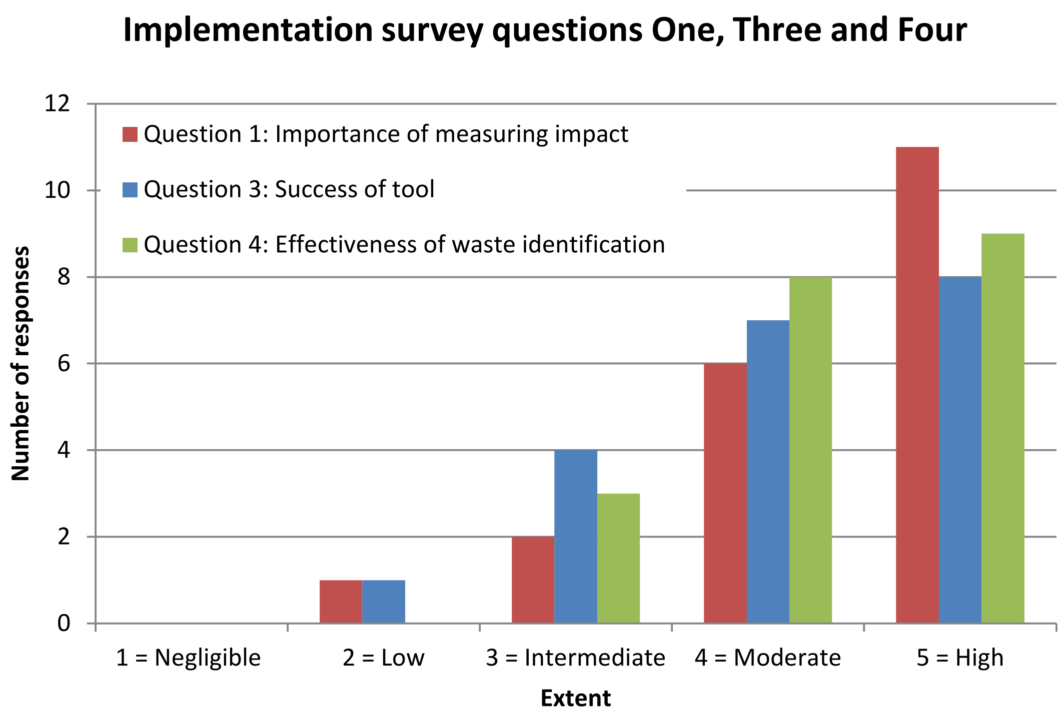


Figure 11: Results of survey questions one, three and four. These results demonstrate effectiveness of the method.

These results show that practitioners understood the importance of measuring the impact of environmental waste (Q1). They felt the tool was successful in promoting new thinking and continuous improvement (Q3) and it was effective at identifying environmental waste (Q4). The practitioners also felt the tool helped sensitise the user to the environmental impact of processes, as well as show actual process level data attributing overall site-wide data to the source of environmental waste impact. We therefore conclude that the tool was successful in achieving the primary purpose as the survey results scored above 85 % for each questions.

6.0 Discussion

6.1 Outcomes: what has been achieved?

This work has made several contributions to the body of knowledge regarding environmental value stream mapping and lean manufacturing principles. The first contribution is the creation of a method to integrate environmental impacts and lean methods. Specifically we have shown integration from the generic *environmental standard* ISO14001, through to an *organisational environmental risk register*, onwards to integration within the *VSM process*, and thus finally permitting the established lean *improvement process* (e.g. kaizen) to be focussed at specific environmental improvement actions. Thus we have found a way to take the abstract concepts of environmental waste and make them concrete. Specifically, we have developed a method to operationalise environmental waste within the VSM lean method. This methodology is shown in Figure 12.

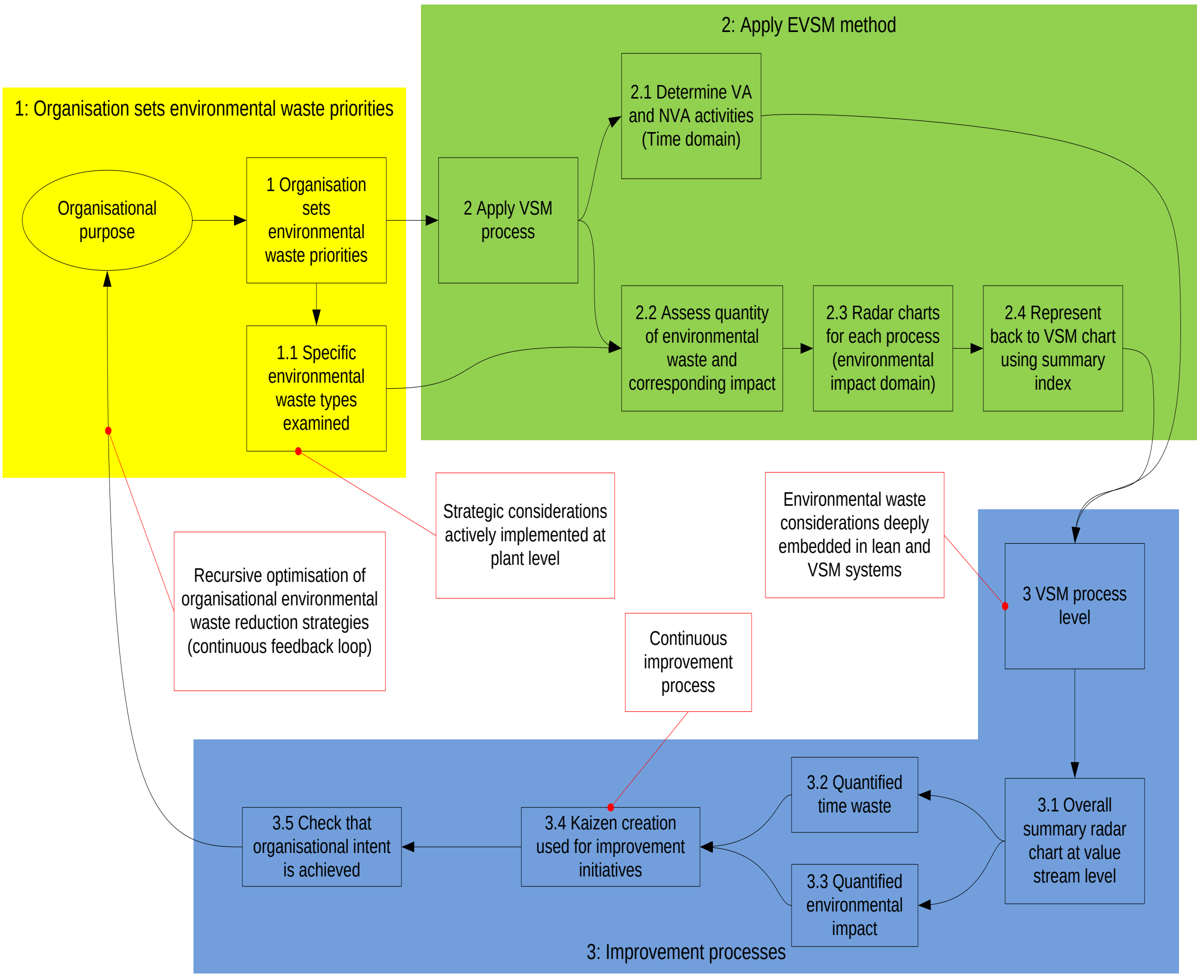


Figure 12: Summary of the overall method as implemented in industry.

A second contribution is the development of an nth dimension environmental factor methodology to create a *customised* environmental waste index for a particular industry. While the index created for this specific case used carbon footprint, perceived impact, cost to remediate, and waste volumes (removed and residual), the method is capable of being generalised to use different factors as well as any number of factors.

A third advancement is that we developed a way to use *ambiguous user estimates* of the quantity of each type of waste. This is important because it provides a basis for estimating values that are imprecise and otherwise difficult for operators to commit to a single deterministic value. Thus, the method is capable of identifying areas for improvement (which is the overall purpose) despite ambiguous and imperfect information. To achieve this, we used the PERT beta distribution, which already has acceptance in the project-management field.

A fourth contribution is the design of a way to represent the multi-dimensional environmental wastes that are relevant to diverse industry situations. Specifically we have used radar charts to help display process level environmental impacts to overall system data as well as and attribute environmental impacts to the source of the problem. This concept also allows the practitioner to drill down or up from a process to an overall system level (or vice versa) for the required information.

6.2 Implications for practitioners

Industry practitioners at the production level now have a method to identify specific improvement activities (e.g. Kaizen) for environmental waste consistent with the organisational priorities. Thus, environmental waste can be considered alongside other forms of waste during the VSM process (see Figure 12). To implement this, production engineers and supervisors would thus apply the environmental waste considerations as part of VSM; see action 2.2 in Figure 12. Then Kaizen solutions are developed Kaizen in the normal manner. Optionally, they can also report back to senior management against objectives for environmental waste, and can do so at the level of whole value streams or individual processes.

Complementary to that, senior management now have a method to take the external environmental standard ISO14001, and develop a customised construct for environmental waste for their particular organisation. They can then align the production processes, particularly the priorities going into the continuous improvement processes, to achieve those organisational objectives. Thus, the method provides a strategic tool for firms that seek to improve their environmental position as summarised in Figure 12. A further implication from a management perspective is that the method has been developed with implementation and change management in mind. It has been specifically designed to be easy to implement and to fit in with existing organisational cultures. It achieves this by being complementary to the established practices of lean and VSM in particular. It takes advantage of practices and ideas with which the organisation is already familiar.

To implement this method, executives and production managers would decide on *which* environmental wastes to include and *set* the priorities for each (see Activity 1, in Figure 12). Production staff would then implement this alongside the usual VSM processes. One of the quality staff would need training to use the method, but widespread training of other staff is not necessary (provided they already know how to implement VSM). Executives can then request summary information on overall environmental waste burden and efficacy of improvement measures. They can then use this information to further refine the strategic approach to managing the environmental waste.

There are many other industries that use lean principles, such as service organisations and project management. The method derived here is generic and not limited to manufacturing, and therefore has potential applicability to these other areas. All organisations, including service firms, can identify waste priorities, assess their waste impacts, and implement Kaizen improvements. The concept of time is particularly relevant to service industries, so value stream mapping is a particularly relevant lean tool in these situations.

6.3 Limitations and opportunities for further research

During the implementation of the described method, several bottlenecks in usability of the system were discovered. The most notable bottleneck was the calculation component when determining the carbon footprint for each stage of the EVSM. This was remedied through the inclusion of an excel spreadsheet that determined carbon footprint for any process. The application of the method was also limited by the level of understanding of the practitioner with respect to environmental impacts and actual process level data instead of overall site level data.

An obvious limitation is that although we have integrated *environmental waste* with *lean manufacturing* practices, the integration is only for value stream mapping. There are many other lean methods, and not all organisations use VSM. Where *time* is the main driver of cost or quality, then VSM is appropriate, but this is not relevant to the production economics of all organisations. At present the integration has only been demonstrated for the manufacturing industry. Consequently there are opportunities for future research to extend and adapt the method to other situations.

7.0 Conclusion

This work develops a method to integrate evaluation of environmental impacts and lean methods. The method has been developed and tested in a manufacturing setting and is able to represent a variety of environmental wastes within the value stream mapping (VSM) method. Specifically, it integrates from generic *environmental standard* ISO14001, through to *organisational environmental risk register*, onwards to integration within the *VSM process*, and thus finally permitting the established lean *improvement process* (e.g. kaizen) to be focussed at specific environmental improvement actions. The deployment used carbon footprint, perceived impact, cost to remediate, and waste volumes (removed and residual), but the method is capable of being generalised to n^{th} dimension environmental factors. It is thereby able to represent a *customised* environmental waste index for a particular industry. A*mbiguous user estimates* of waste quantities are accommodated through the PERT beta distribution. Several ways to represent the multi-dimensional environmental wastes were explored via industry focus groups and the preferred representation designed to completion. The resulting method can be used by production staff and represents environmental impacts at the level of the individual process and aggregated to the whole value stream. The method may also be used by executives to align organisational practices with strategic objectives for waste reduction.

Acknowledgements

We acknowledge the support of the Christchurch Engine Centre, New Zealand, particularly Tim Coslett for hosting and supporting this project.

Appendix: Implementation of VSM

A VSM requires five steps that can then be applied to information, material or process flow. A brief summary of the five steps is provided (Womack and Jones 1996; Rother and Shook 1999).

Identify target product, family or service

This stage requires the translation of customer requirements into process requirements. The customer base can be both external and internal and is described as those who accept, evaluate, install /inspect, own and use products or services.

Map current state

Creating a current state VSM requires a team of people (who both manage and support various parts of the value stream) and who have been closely associated or involved with the process or information flow. Once the critical value stream has been chosen, every task or component is noted in the order that it is required to complete the service or product, starting at the shipping process and working backwards in the value stream to the raw materials or suppliers, while collecting information at each stage (Seth and Gupta 2005; Braglia, Carmignani et al. 2006).

Assess current VSM in terms of creating a better flow by eliminating waste

Once the current state map has been completed, an assessment should be carried out to determine which processes add value. This step requires the identification of all Value Added (VA) and Non-Value Added (NVA) activities, as well as Necessary but Non-Value Adding (NNVA). A common exercise used during this operation is the lean implementation tool called a “Kaizen burst” in which areas that represent large amounts of NV added time (Lead time) are targeted and reduced or eliminated. In this circumstance, a Kaizen event is one in which a process is critically reviewed to determine areas which could be improved.

Draw future state VSM

Once the target waste (Kaizen initiatives) areas are identified, an ideal future state map (FSM) should be determined. This map should represent how the value stream will look after the identified waste has been eliminated and all Kaizen implemented. The FSM should be indicative of a situation in which all the individual processes produce only what its customer/process needs (or as close as possible) and only when required.

Work toward the future state condition

The final stage in VSM analysis is the creation and implementation of a work plan to accomplish the waste reduction goals identified whilst determining the FSM. The implementation plan describes how the goals set whilst creating the FSM are going to be achieved. Waste identification is a crucial element of any VSM as it is indicative of the Kaizen events held to reduce NVA activities. Some common reasons for waste within an information or manufacturing system are as follows (Oppenheim 2004):

- Push rather than pull based specifications and requirements
- Non-optimal use of human resource (e.g. using the wrong staff to do the wrong job such as a manager level or high engineering level staff doing NVA or NNVA work.)
- Lack of detail, lack of organisation in planning, lack of leadership and management
- Use of obsolete two-dimensional drawings instead of single point release database with three-dimensional data.

References

Abdulmalek, F. A. and J. Rajgopal (2007). "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study." International Journal of Production Economics **107**: 223-236.

Balogun, J. and M. Jenkins (2003). "Re-conceiving Change Management:: A Knowledge-based Perspective." European Management Journal **21**(2): 247-257.

Biloslavo, R. and A. Trnavcevic (2009). The factors of choice of change methods: what is their impact on consequences of change? PICMET '09 - 2009 Portland International Conference on Management of Engineering & Technology, 2-6 Aug. 2009, Piscataway, NJ, USA, IEEE.

Bontoux, L. and F. Leone (1997). The Legal Definition of Waste and its Impact on Waste Management ind Europe. E. C. (EU). Spain, Institute for Prospective Technological Studies. **European Directive 75/442/EC as amended**.

Braglia, M., G. Carmignani, et al. (2006). A new value stream mapping approach for complex production systems, Taylor and Francis Ltd.

Braungart, M., W. McDonough, et al. (2007). "Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design." Journal of Cleaner Production **15**(13–14): 1337-1348.

Brinkley, A., M. Karlsson, et al. (2000). Systematic environmental assessment: a decision methodology for strategic environmental issues. Electronics and the Environment, 2000. ISEE 2000. Proceedings of the 2000 IEEE International Symposium on.

Cabrera, Á., E. F., et al. (2001). "The key role of organizational culture in a multi-system view of technology-driven change." International Journal of Information Management **21**(3): 245-261.

Carnall, C. A. (1995). Managing Change in Organisations, Prentice Hall, London.

Chen, J. C., L. Ye, et al. (2010). "From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study." International Journal of Production Research **48**: 1069-1086.

Chu, K. F. (2003). "An organizational culture and the empowerment for change in SMEs in the Hong Kong manufacturing industry." Journal of Materials Processing Technology **139**(1–3): 505-509.

David, P. (1996). "The project management of organizational change." International Journal of Project Management **14**(1): 13-21.

Deming, W. E. (1986). Out of the crisis. Cambridge, MIT Press.

Diefenbach, T. (2007). "The managerialistic ideology of organisational change management." Journal of Organisational Change Management **20**(1): 126-144.

Dyck, B. and F. A. Starke (1999). "The formation of breakaway organizations: Observations and a process model." Administrative Science Quarterly **44: 792**.

EPA (2000). Pursuing Perfection: Case studies examining lean manufacturing strategies. U. S. Environmental Protection Agency. Washington D.C.

EPA (2003). Lean Manufacture and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recomendations for Leveraging better Environmental Performance. U. S. Environmental Protection Agency. Washington D.C.

EPA. (2011). "EPA, The lean and Environmental Toolkit."   Retrieved 22/08/2011.

Grebe J.C, Jr. (2001). Effective engineering management in the next decade. Change Management and the New Industrial Revolution (IEMC'01), October 7, 2001 - October 9, 2001, Albany, NY, United states, Institute of Electrical and Electronics Engineers Inc.

GRI (2006). G3 Stustainability Reporting Guidelines. Amsterdam, Global Reporting Initiative.

Gurumurthy, A. and R. Kodali (2011). "Design of lean manufacturing systems using value stream mapping with simulation A case study." Journal of Manufacturing Technology Management **22**(4): 444-473.

Hart, S. and G. Ahuja (1995). "A Natural Resourced Based View of the Firm." Academy of Management Review **20**(4): 985-1014.

Hicks, B. J. (2007). "Lean information management: understanding and eliminating waste." International Journal of Information Management **27**: 233-249.

Hines, P., M. Holwe, et al. (2004). "Learning to evolve: a review of contemporary lean thinking." International Journal of Operations & Production Management **24**: 994-1011.

Hines, P. and N. Rich (1997). "The seven value stream mapping tools." International Journal of Operations & Production Management **17**: 46-46.

Hokerby, I. (1993). "Environmentally Compatible Product and Process Development." NAE Workshop on Corporate Environmental Stewardship.

Irani, S. (2004). Value Network Mapping (VNM): Visualization and analysis of multiple interacting value streams in jobshops. 4th Annual Lean Management Solutions Conference 2004, Sep 12 - 16 2004, Los Angeles, CA, United states, Institute of Industrial Engineers.

ISO:14031 (2000). Environmental Managment - Environmental Performance Evalutation Guidelines, ISO 14031:2000. Geneva: International Organization for Standards.

ISO:14040 (2006). Environmental management - Life cycle assesment - Principles and framework; ISO 14040:2006. Geneva: International Organization for Standards.

Jasch, C. (2003). "The use of Environmental Management Accounting (EMA) for identifying environmental costs." Journal of Cleaner Production **11**(6): 667-676.

Karlsson, C. and P. Ahlstrom (1996). "Assessing changes towards lean production." International Journal of Operations & Production Management **16**(2): 24-41.

Kezar, A. J. (2001). "Understanding and Facilitating Organisational Change in the 21rst Century." ASHE-ERIC Higher Education Report **Volume 28 Number 4**.

King, A. A. and M. J. Lenox (2001). "Lean and green? An empirical examination of the relationship between lean production and environmental performance." Production and Operations Management **10**: 244-256.

Kotter, J. P. (2009). "Leading change: Why transformation efforts fail." IEEE Engineering Management Review **37**(3): 42-48.

Kotter, P. J. (2007). "Leading change - why transformation efforts fail." Harvard Business Review **85**(1): 96-103.

Kuhlang, P., T. Edtmayr, et al. (2011). "Methodical approach to increase productivity and reduce lead time in assembly and production-logistic processes."

Kurstedt Jr, H. A., L. A. Mallak, et al. (1990). Why engineers must know and manage organizational culture. 1990 International Engineering Management Conference, October 21, 1990 - October 24, 1990, Santa Clara, CA, USA, Publ by IEEE.

Lasa, I. S., R. de Castro, et al. (2009). "Extent of the use of Lean concepts proposed for a value stream mapping application." Production Planning and Control **20**: 82-98.

Lian, Y. H. and H. Van Landeghem (2007). "Analysing the effects of Lean manufacturing using a value stream mapping-based simulation generator." International Journal of Production Research **45**: 3037-3058.

McDonough, W. and M. Braungart (2002). Cradle to cradle: Remaking the way we make things, North Point Press.

Melton, T. (2005). "The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries." Chemical Engineering Research and Design **83**(6): 662-673.

Monden, Y. (1993). Toyota Production System: An Integrated Approach to Just-in-Time, Industrial Engineering and Management Press: Norcross, GA.

Morgan, G. (2006). Images of Organisations, Sabe Publications, California.

Navarre, C. and J.-L. Schaan (1987). "International engineering project management: key success factors in a changing industry." International Journal of Project Management **5**(4): 238-245.

Oppenheim, B. W. (2004). "Lean product development flow." Systems Engineering **7**: 352-376.

Patil, A. S. (2002). Incorporating environmetnal index as waste into value stream mapping. Mechanical Eningeering, Masters of Science, Major of Industrical Engineering. Wichita, Wichita State University,**:** 93.

Pohjola, V. J. and E. Pongrácz (2002). "An approach to the formal theory of waste management." Resources, Conservation and Recycling **35**(1–2): 17-29.

Pongrácz, E. and V. J. Pohjola (2004). "Re-defining waste, the concept of ownership and the role of waste management." Resources, Conservation and Recycling **40**(2): 141-153.

Richards, D. (1994). "Environmentally Consious Manufacturing." World Class Design to Manufacture **1**(No 3): 15-22.

Rother, M. and J. Shook, Eds. (1999). Learning to see: value stream mapping to add value and eliminate MUDA, The Lean Enterprise Institue, Brookline, MA.

Salhofer, S., G. Wassermann, et al. (2007). "Strategic environmental assessment as an approach to assess waste management systems. Experiences from an Austrian case study." Environmental Modelling & Software **22**(5): 610-618.

Schein, E. H. (1990). "Organisational Culture." American Psychologist **45**: 109-119.

Serrano, I., C. Ochoa, et al. (2008). "Evaluation of value stream mapping in manufacturing system redesign." International Journal of Production Research **46**: 4409-4430.

Seth, D. and V. Gupta (2005). "Application of value stream mapping for lean operations and cycle time reduction: An Indian case study." Production Planning and Control **16**: 44-59.

Singh, B., S. K. Garg, et al. (2011). "Value stream mapping: Literature review and implications for Indian industry." International Journal of Advanced Manufacturing Technology **53**: 799-809.

Singh, B. and S. K. Sharma (2009). "Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm." Measuring Business Excellence **13**: 58-68.

Tapping, D., T. Luyster, et al. (2002). Value Stream Management, Productivity Press, A Division of Kraus Productivity Organization.

Torres, A. S., Jr. and A. M. Gati (2009). Environmental Value Stream Mapping (EVSM) as sustainability management tool. PICMET '09 - 2009 Portland International Conference on Management of Engineering & Technology, 2-6 Aug. 2009, Piscataway, NJ, USA, IEEE.

Van de Ven, A. H. and M. S. Poole (1995). "Explaining development and change in organisations." Academy of Management Review **20**.

Wiedmann, T. and J. Minx (2008). Chapter 1, A defintion of "Carbon Footprint". In C.C Pertsova, Ecological Economics Reserach Trends. New York, Nova Science Publishers.

Womack, J., D. Jones, et al. (1991). The Machine That Changed the World : The Story of Lean Production, {Harper Perennial}.

Womack, J. P. (2006). "Value stream mapping." Manufacturing Engineering **136**: 145-145.

Womack, J. P. and D. T. Jones (1996). Lean thinking: Banish waste and create wealth in your corporation. London, Simon and Schuster.

Worcester, R. M. (1970). "Managing change." Long Range Planning **3**(1): 31-35.